BASIS AND BACKGROUND DOCUMENT
IMPACT TO GROUND WATER PATHWAY

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PATHWAY HIGHLIGHTS

A. Purpose

- The impact to ground water soil remediation standards are designed to prevent the unacceptable risk to human health from the ingestion of contaminated ground water caused by the migration of chemicals from the unsaturated soil zone to the ground water. It is not appropriate to use the impact to ground water standards to determine when a ground water sample should be collected. The Technical Requirements for Site Remediation will be amended to be consistent with this approach.

B. Lower Generic Impact to Ground Water Standards

- The generic impact to ground water standards will be protective of Class II-A ground waters at sites where site specific information is not available. To ensure an adequate margin of safety in the absence of site specific information, the resulting generic impact to ground water standards are conservative. As a result, more sites will need to conduct site investigations for this pathway.

C. Updated Models and Methodologies

In February of 1992 the Department proposed Subsurface Soil Cleanup Standards for the Soil-to-Ground Water Pathway. These standards were never adopted but have been used by the Department as Soil Cleanup Criteria. For this current effort, the Department has decided to use USEPA's simple partitioning equation that is presented in the May 1996 USEPA "Soil Screening Guidance: Technical Background Document" (USEPA, 1996) and other USEPA methodologies, in accordance with N.J.S.A.58:10B-12. As a result, the generic impact to groundwater standards proposed here are, in many instances, more conservative than the 1992 Soil Cleanup Criteria. The major differences between the 1992 and the current standards development effort are noted below.

(1) Volatile Organic Compounds

The following assumptions were used in deriving the 1992 proposed Subsurface Soil Standards for the Soil-to-Ground Water Pathway for volatile organic compounds:

- The concentration of contaminants in ground water was averaged over a 70 year time. This assumption resulted in the ground water quality standards being exceeded for some period of time at the beginning of the 70 year period.

- A 6 foot clean soil zone between the contaminated soil and ground water assumed.

- All subsurface soil standards that were calculated to be lower than 1 mg/kg were, based on policy, increased to 1 mg/kg.

The current impact to ground water soil remediation standards make the following related assumptions.

- A 70 year time-averaged ground water standard is not used. Instead the simple partitioning model generates standards that are protective of ground water quality immediately in all cases.

- The proposed impact to ground water soil remediation standards assume that soil contamination is present at the water table.

- The proposed to ground water soil remediation standards are calculated and subjected to a generally accepted method of rounding or may be modified based on PQLs.

(2) Semi-Volatile Organic Compounds, Pesticides and PCBs
The 1992 proposed Subsurface Soil Cleanup Criteria for the Soil-to-Ground Water Pathway for semi-volatile organic compounds were derived using an arbitrary ranking system based on solubility, biodegradation and toxicity. A ranking sum was used to determine an arbitrary soil standard. It is now believed that this system may not be protective of ground water. The ranking system is not scientifically valid, and no new semi-volatile criteria have since been developed

using this system. The ranking system is unique to New Jersey, and has no USEPA, other regulatory agency, or scientists' backing. When calculating new semi-volatile criteria, the Department now uses USEPA's simple partitioning model or Synthetic Precipitation Leaching Procedure test results. Furthermore, the ranking system is used only for semivolatiles and therefore there is no consistency in the methodologies used for other classes of contaminants.

(3) Inorganic Chemicals

The 1992 proposed Subsurface Soil Cleanup Criteria for the Soil-to-Ground Water Pathway did not include standards for inorganic chemicals. Consistent with USEPA, the proposed soil standards include remediation standards for inorganic chemicals that are protective of ground water.

D. Several Options for Developing Site-Specific Alternative Remediation Standards

In lieu of using the generic impact to ground water remediation standards, alternative remediation standards can be developed using site specific information and methodology provided by the Department. (See the Impact to Ground Water Basis and Background document) The options for developing site-specific alternative remediation standards are briefly described below:

- Option A. Modify input parameters in the simple partitioning equation using site specific data such as soil pH and soil organic carbon content. Calculate the site specific remediation standard.

- Option B. Determine whether the contaminant is on a list of immobile chemicals the Department has developed. Chemicals on the list might not require remediation to the generic impact to groundwater remediation standards provided that all of the caveats and conditions specified are met, such as an adequate clean zone above the water table.

- Option C. Perform the Synthetic Precipitation Leaching Procedure (SPLP) to determine the site specific leaching potential for inorganics, semi-volatile organics, and pesticides. Calculate the site specific remediation standard.

- Option D. Conduct transport modeling when soil contamination is present and ground water has not been impacted. Calculate the site specific remediation standard.

- Option E. Conduct vadose zone and ground water modeling when soil contamination is present and ground water has been impacted. Calculate the site specific remediation standard.

- Option F. Evaluate site specific ground water, soil analytical results, and water table conditions. If ground water impacts are not observed, remediation to the generic standards might not be required provided that all of the caveats and conditions specified are met.

E. Compliance

- Compliance sampling for the impact to ground water pathway continues to be conducted on a point-by-point basis.
- An alternate compliance sampling approach option is available for the monitored natural attenuation of petroleum hydrocarbon contaminated soil.

All of the above are discussed in greater detail in this Basis and Background document.

I. Introduction

The purpose of the Impact to Ground Water Soil Remediation Standards is to prevent the unacceptable risk to human health from the ingestion of contaminated ground water, caused by the migration of chemicals from the unsaturated soil zone to the ground water.
The Brownfield and Contaminated Site Remediation Act N.J.S.A. 58:10B-12c(1) directs the New Jersey Department of Environmental Protection (the Department) to develop soil remediation standards that are protective of ground water for contaminants that are mobile and transportable to ground water. The well established policy of this state is "to restore, enhance and maintain the chemical, physical, and biological integrity of its waters…" Water Pollution Control Act, N.J.S.A 58:10A-1. This section describes the basis and background for soil remediation standards applicable for the soil to ground water pathway.

The standards are developed to address site investigations and remedial investigations where varying amounts of site information are available. Generic standards are developed for use in situations where little site-specific information is available and/or where general and conservative assumptions are adequate for completing soil remediation work. These standards are listed in Section III, Table of Generic Standards.

Alternative remediation standards (ARS) can be calculated when site-specific information is available in lieu of the default input parameters used in the calculation of the generic standards. The methodologies for developing ARS are detailed in Section IV.

The standards were developed considering the laws and regulations pertinent to the Site Remediation and Waste Management Program as discussed below.

The Brownfield and Contaminated Site Remediation Act, N.J.S.A. 58:10B-12

The Legislature directed the Department to develop minimum remediation standards using the following criteria: *"base the standards on generally accepted and peer reviewed scientific evidence or methodologies."*

The Department is using the methodologies described in the USEPA Soil Screening Level (SSL) Guidance Document (USEPA, 1996b) for the generic Impact to Ground Water Soil Remediation Standards (IGWSRS). The USEPA SSL methodology uses a partitioning equation to calculate chemical specific concentrations in soil that are protective of ground water. This document uses only well established models that are generally accepted by the scientific community.

"base the standards upon reasonable assumptions of exposure scenarios as to amounts of contaminants to which humans or other receptors will be exposed, when and where those exposures will occur, and the amount of that exposure."

The Class II-A ground water quality criteria at N.J.A.C. 7:9-6 et seq., are developed considering the above exposure scenario, which is based on the protection of human health. The health-based Class II-A ground water quality criteria are the applicable endpoints from which the impact to ground water soil remediation standards are calculated. The generic standards apply only to Class II-A aquifers. Site-specific impact to ground water standards must be developed for all other aquifer classifications (for example Class I-A Pine Barrens). This is discussed more fully in the Compliance section.

"avoid the use of redundant conservative assumptions. The department shall avoid the use of redundant conservative assumptions by the use of parameters that provide an adequate margin of safety and which avoid the use of unrealistic conservative exposure parameters and which guidelines make use of the guidance and regulations for exposure assessment developed by the United States Environmental Protection Agency pursuant to the "Comprehensive Environmental Response, Compensation, and Liability Act of 1980," 42 U.S.C. §9601 et seq. and other statutory authorities as applicable;"

There are two mandates stated in the above citation. First, a balance is required between achieving an adequate margin of safety and avoiding unrealistic conservative assumptions. To ensure an adequate margin of safety in the absence of site-specific information, the assumptions used to develop generic standards are reflective of realistic conditions occurring in New Jersey.

Second, it is necessary to use the guidance and regulations for exposure assessment developed by the United States Environmental Protection Agency. For purposes of these regulations, the relevant guidance is the USEPA SSL Guidance Document (USEPA, 1996b). Variations from USEPA's procedures will be allowed if it can be justified and reflect New Jersey-specific information.

The Ground Water Quality Standards (N.J.A.C. 7:9–6)

"The Department shall preferentially protect the primary designated use for each classification area…" (NJAC 7:9-6.5b)

The primary designated use for Class II-A ground water is potable water. Class II-A consists of all ground water of the State, except for ground water designated in Classes I, II-B or III. The generic impact to ground water soil remediation standards are developed to protect the Class II-A primary designated use (potable water). Protection of Class I, II-B and III are discussed in the Compliance Section of this document.

"N.J.A.C. 7:9-6.1(a) It is the policy of this State to restore, enhance and maintain the chemical, physical, and biological integrity of its waters…"

The generic impact to ground water soil remediation standards are developed to protect ground water from future impacts emanating from contaminated unsaturated soils. The generic IGWSRS will help to restore ground water quality at sites with contamination through source remediation.

Options for developing Alternative Remediation Standards to maintain uncontaminated ground waters are available. In addition, ground water that is already contaminated must be restored.

Options are included to make it possible to develop area-specific impact to ground water soil remediation standards that are less stringent than the generic standards but will enhance ground water conditions over time.

II. Methodology for Developing Generic Impact to Ground Water Remediation Standards

A. Simple Partitioning Equation

Consideration of the mandates discussed above led to the Department's decision to use the USEPA SSL Partitioning Equation approach to calculate the generic impact to ground water soil remediation standards. The methodology back calculates a concentration in soil from an acceptable ground water concentration (the Class II-A GWQC). The simple partitioning approach satisfies the mandate to use procedures similar to USEPA guidance whenever possible; in fact it uses guidance given by the USEPA's Superfund program, which is analogous to the Department's Site Remediation and Waste Management Program. The simple partitioning approach assumes that the contaminant is present in soil immediately adjacent to the water table, and thus protects ground water in these scenarios. It is also compatible with the Legislature's ground water protection mandates.

The Brownfield and Contaminated Site Remediation Act (N.J.S.A. 58:10B-12) requires the Department to avoid the use of redundant conservative or unrealistic assumptions when determining remediation standards. For this reason, a balance of "conservative" and "typical" values for input parameters are used when calculating generic remediation standards. "Conservative" values, while being protective, are reflective of conditions that actually occur in the state. "Typical" values should be reflective of common conditions, or conditions that are in between the extremes observed in New Jersey. Thus, the resulting generic remediation standards are reasonably conservative, and avoid unrealistic conservative assumptions.

The central principles of the simple partitioning equation are as follows. The USEPA SSL partitioning equations (USEPA, 1996b, Equations 22 and 24) assume that contaminants in soil exist in equilibrium between the sorbed phase (on soil solids), aqueous phase (in soil moisture) and vapor phase (in the soil airspace). The equations calculate the total amount of the contaminant that may be left behind in the soil such that the aqueous phase concentration of the contaminant will not exceed a specified criterion. The criteria for New Jersey are the health-based ground water quality criteria. Since soil water will actually be diluted once it enters the ground water, a dilution-attenuation factor (DAF) is included in the equation to account for this process. Dilution of the contaminant due to transport through the unsaturated soil zone is not included; the chemical in soil is assumed to be immediately adjacent to the water table. Chemical degradation is also not included in this model; the calculations assume that ground water quality must be achieved immediately after remediation.

The equations for calculating the generic Impact to Ground Water standards are given below. The USEPA SSL equations 24 and 22 are adapted for organic and inorganic contaminants, respectively. For New Jersey purposes, the equations (shown below as Equations 1 & 2) are expanded to separate the target leachate concentration discussed in the USEPA document into its component parts. The target leachate concentration is the product of the ground water criteria (C_{gw}), and the dilution-attenuation factor (DAF). This modification allows the New Jersey ground water quality criteria to be directly entered as an input parameter. The DAF is calculated via Equation 3. This equation requires a value for the mixing zone depth in the aquifer, which is calculated using Equation 4. These two equations are taken from USEPA SSL Guidance Document (USEPA, 1996b, Equations 37 and 45), respectively.

B. Equations for Calculating Generic Impact to Ground Water Soil Remediation Standards

Organic contaminants:

$$IGWSRS = C_{gw}\left\{(K_{oc}f_{oc}) + \frac{\theta_w + \theta_a H'}{\rho_b}\right\}DAF$$ Equation (1)

Inorganic contaminants:

$$IGWSRS = C_{gw}\left\{(K_d) + \frac{\theta_w + \theta_a H'}{\rho_b}\right\}DAF$$ Equation (2)

Where:

IGWSRS = Impact-to-ground water soil remediation standard (mg/kg)
Cgw = Health Based New Jersey Ground Water Quality Criteria (mg/L)
Koc = Soil organic carbon-water partition coefficient (L/kg)
foc = organic carbon content of soil (kg/kg)
Kd = soil-water partition coefficient (L/kg)
θ_w = water-filled soil porosity (L_{water}/L_{soil})
θ_a = air-filled soil porosity (L_{air}/L_{soil})
H' = Henry's law constant (dimensionless)
ρ_b = dry soil bulk density (kg/L)
DAF = dilution-attenuation factor, calculated below (Equation 3)

<u>Equation for calculating the dilution-attenuation factor (DAF):</u>

$$DAF = 1 + \frac{Kid}{IL}$$ Equation (3)

Where:
i = gradient (m/m)
d = mixing zone depth (m), calculated below (Equation 4)
I = infiltration rate (m/yr)
L = length of area of concern parallel to ground water flow (m)
K = aquifer hydraulic conductivity (m/yr)

<u>Equation for calculating the aquifer mixing zone depth, *d*:</u>

$$d = (0.0112L^2)^{0.5} + d_a\{1 - \exp[(-LI)/(Kid_a)]\}$$ Equation (4)

Where:
d_a = aquifer thickness (m)

C. Discussion of Default Input Parameters

The methodology to calculate generic remediation standards necessitates assigning default values to all input parameters for Equations 1-4 above. The default values used by USEPA in the SSL guidance document are derived from nationwide data for each of the input parameters. Some parameters, such as chemical properties, do not follow region-specific trends. For these, the USEPA default values are used. For other parameters, such as soil properties and applicable ground water criteria, values more specific to New Jersey conditions are warranted. A comparison of the USEPA and the Department's default parameters are listed below, followed by an individual discussion of each input parameter. A sensitivity analysis showing the effect of varying parameters was conducted and the results are presented in Appendix B.

Table 1. Default Values for Generic IGWSRS calculations

	EPA Default Value	DEP Default Value
Groundwater criteria, C_{gw} (mg/L)	MCL or MCLG	GWQC
Soil organic carbon-water partition coefficient, K_{oc} (L/kg)	chemical specific	chemical specific
Soil-water partition coefficient, K_d (L/kg)	chemical specific	chemical specific
Henry's law constant at 25°C, H' (dimensionless)	chemical specific	chemical specific
Soil pH	6.8	4.9 or 6.8
Soil texture	loam	sandy loam
Soil porosity (v/v)	0.43	0.41
Fraction organic carbon, f_{oc} (kg/kg)	0.002	0.002
Water content, θ_w (L_{water}/L_{soil})	0.3	0.23
Air content, θ_a (L_{air}/L_{soil})	0.13	0.18
Dry soil bulk density, ρ_b (kg/L)	1.5	1.5
DAF	20	12
Aquifer hydraulic conductivity*Gradient, K *i(m/yr)	none[a]	30
Mixing zone depth, d (m)	none[a]	3.05
Infiltration rate, I (m/yr)	none[a]	0.28
Length parallel to groundwater flow, L (m)	45	30.5
Aquifer thickness, d_a*(m)*	none[a]	3.05
[a] **Monte Carlo distribution used**		

D. New Jersey Ground Water Quality Criteria (C_{gw})

USEPA value: Maximum Contaminant Level Goal (MCLG) or Maximum Contaminant Level (MCL)
NJDEP value: Ground Water Quality Criteria (health-based)

For ground water protection, New Jersey must use the criteria listed in the Ground Water Quality Standards (N.J.A.C. 7:9-6) and its subsequent updates. These criteria are often lower than USEPA's corresponding criteria. The health-based ground water quality criteria are used as input parameters, rather than the ground water Practical Quantitation Levels (PQLs). As shown in the sensitivity analysis in Appendix B the remediation standard is directly proportional to the value of the ground water criteria.

E. Chemical Properties of Contaminants

Chemical properties for all regulated contaminants are listed in Appendix C. When possible, chemical properties are taken from values in USEPA's SSL Guidance document (USEPA, 1996b). For chemicals not listed in the USEPA SSL Guidance document, properties are obtained using the same data sources that USEPA used in its guidance document. The Superfund Chemical Data Matrix (USEPA, 1996c) was used to obtain water solubilities and Henry's Law constants.

K_{oc} values (for chemicals not listed in the guidance document) are calculated from octanol-water partition coefficients developed by USEPA using Equations 70 or 71 provided in the USEPA SSL document. Octanol-water coefficients are obtained from the Superfund Chemical Data Matrix. For ionizable organic chemicals, Table 42 of the USEPA SSL Guidance document lists K_{oc} values for pH 4.9, 6.8 and 8.0. The pH selected for New Jersey remediation standard calculations was 6.8, corresponding to the upper limit of the New Jersey soil pH range (see below). This maximized mobility of the contaminant (lowest K_{oc} value). K_d values are used for inorganic contaminants. Some of these contaminants have pH-dependant K_d values listed in the

USEPA SSL guidance document. For these contaminants, the K_d values chosen are those listed at either pH 4.9 or 6.8 (Table 46 of the USEPA, SSL Guidance document), whichever maximized the mobility of the contaminant (lowest K_d value). These two pH values are appropriate for New Jersey soils (see below). When not listed in the USEPA, SSL guidance document, K_d values are taken from the Superfund Chemical Data Matrix. The Hazardous Substances Data Bank was used as a data source when the above data sources did not contain the needed information (HSDB, 1999). The few exceptions to the above procedures are footnoted in the chemical property table (Appendix C). The remediation standard is most sensitive to a chemical's K_{oc} or K_d value (Appendix B). The Henry's law constant has a relatively small effect (Appendix B).

Soil pH

USEPA value: 6.8

NJDEP value: 4.9 or 6.8

Although soil pH is not a direct input parameter in the simple partitioning equation, it may affect the K_{oc} value for ionizable organic contaminants, and the K_d value for inorganic contaminants. The default pH of 6.8 used in the USEPA, SSL guidance document is an overall average pH for United States soils. However, it is well known that soils in the eastern United States are more acidic than those in the western part of the country (Foth, 1984). Therefore, it is appropriate to use New Jersey-specific information regarding soil pH. The pH of New Jersey soils typically range from about pH 4 to pH 6.5 (Lee et al., 1996, Yin et al., 1996). The USEPA SSL Guidance document lists pH-dependant adsorption coefficients (K_{oc} or K_d values) for several contaminants at pH 4.9, 6.8 and 8.0 (Table 46 of the USEPA, SSL Guidance document. The two lower pH values are appropriate for New Jersey use. The pH value chosen (4.9 or 6.8) was that which minimized the value of the contaminant's K_d parameter (see previous section).

Soil Texture

USEPA: loam

NJDEP: sandy loam

Soil texture is not a direct input parameter in the simple partitioning equation. However, several of the parameters in the simple partitioning equation are affected by soil texture. These are bulk density, air content, water content and infiltration rate. The first three parameters only minimally affect the calculated remediation standard (Appendix B). However, the infiltration rate does significantly affect the dilution-attenuation factor (DAF, in Equations 1 and 2) which is part of the simple partitioning equation. Heavier soils (such as loam soils, or those with significant clay content) retard water infiltration through soil relative to sandy loam soil or sand, and therefore raise the value of the DAF. The USEPA uses loam as its default soil texture based on nationwide data. However, because the entire southern half of New Jersey is primarily composed of sandy loam and sand soils (Tedrow, 1986), it was felt that a loam soil texture was inadequately protective of the state. A sandy loam soil was selected as the generic soil texture, which is more representative of hydrologic conditions in southern New Jersey than loam soil. Sand was not used as the default soil texture because sand is too porous to be representative of northern New Jersey, and is primarily located in the Pine Barrens of New Jersey and in coastal areas, where relatively few hazardous waste sites are located. For these reasons the use of a sandy loam soil texture for a default parameter is most appropriate for New Jersey.

Soil Porosity

USEPA value: 0.43

NJDEP value: 0.41

Soil porosity is not directly used in Equations 1 or 2, but is used to calculate soil air content. Soil porosity may range from 0.36 to 0.46 (v/v) (Carsel and Parrish, 1988). USEPA uses the porosity for loam soil, while the Department uses the value for sandy loam soil, which has been selected as the default soil texture for New Jersey. The value is selected from the same data source used by the USEPA (Carsel and Parrish, 1988).

Dry Soil Bulk Density (ρ_b)

USEPA value: 1.5 kg/L

NJDEP value: 1.5 kg/L

Dry soil bulk densities vary over a relatively small range, from about 1.3-1.8 g/cc (Carsel et al., 1988). The USEPA default value was used because it agrees with the value listed for a sandy loam soil texture. The value is from USEPA's Soil Screening Level bulk density data source for soils (Carsel et al., 1988). Remediation standards are only slightly affected by the value of this parameter (Appendix B).

<u>Volumetric Soil Water Content (θw)</u>

USEPA value: 0.3

NJDEP value: 0.23

Soil moisture content is highly specific to soil type and climate (Sanders and Talimcioglu, 1997). The moisture content will vary according to season and short-term weather. In New Jersey, this variation for a sandy loam soil has been estimated to lie within the range of 0.18 to 0.26 (v/v) (Sanders and Talimcioglu, 1997). For purposes of the New Jersey generic remediation standard calculation, it is best to use local climate data to determine an average water content for a targeted soil. The targeted soil texture for New Jersey is sandy loam (discussed above). USEPA's soil moisture value corresponds to a moisture level in between the field capacity of sandy loam soils and the saturation volume for loam soils, and is higher than the actual average moisture level for sandy loam soil in New Jersey (Sanders and Talimcioglu, 1997). For New Jersey, an average soil moisture content specific to sandy loam soil and New Jersey climate and weather conditions was calculated using a simple relationship described in the USEPA SSL User's Guide (USEPA, 1996a). A value of 0.23 (v/v) was calculated. Appendix D contains additional information regarding determination of the generic soil moisture levels. This parameter has only a small effect on the remediation standard (Appendix B).

<u>Volumetric Soil Air Content (θa)</u>

USEPA value: 0.13

NJDEP value: 0.18

Volumetric soil air content is determined from total porosity and soil moisture content. Refer to the discussion of Department values for those two parameters. This parameter has only a small effect on the remediation standard (see Appendix B).

Soil Organic Carbon (f_{oc})

USEPA value: 0.002

NJDEP value: 0.002

Organic carbon content can vary from near zero (beach sands and other sandy soils at subsurface depths) to several percent (surface soils in forests). The organic carbon content of soil has not been well-documented below 1-2 meters in depth, but a statistical approach performed by Carsel et al. (1988) provides a good estimate of a representative value for subsurface soils at about 1 meter depth. Because the organic carbon content of subsurface soils is typically lower than surface soils, the value would be considered to be a reasonably conservative value. This value for 1-meter depth (0.002 w/w) was estimated from a nationwide database (Carsel et al., 1988), and is suitable for use in New Jersey. Increasing the f_{oc} value raises the soil remediation standard.

Saturated Hydraulic Conductivity (K) and Hydraulic Flow Gradient (i)

USEPA: no default value

NJDEP: $K*i$ product = 30m/yr (average of two mean values for Kirkwood Cohansey Aquifer System)

The remediation standard is approximately linear with respect to these two parameters (see Appendix B). These parameters are input parameters used to calculate a DAF. The USEPA used a Monte Carlo approach to determine a generic DAF value, in which it varied all of the input parameters in Equation 3 (including K and i) throughout the range of possible values that might be observed in the United States.

The Department has not accepted the use of the Monte Carlo approach for developing standards. Therefore, the Department's Geographic Information System (GIS) based data were used to determine a generic aquifer flow rate for the Kirkwood-Cohansey aquifer. The approach involved multiplying together hydraulic conductivity and aquifer slope data layers.

The *K* layer was developed using data generated by aquifer pump tests that are conducted for the Department's Water Allocation Program. Measured values for hydraulic conductivity are obtained from over 100 properly conducted pump tests. Values between the measured points are interpolated using Bayesian mapping techniques.

To obtain a hydraulic gradient data layer, two approaches were used. The first used a generally accepted procedure for the New Jersey coastal plain that assumes the hydraulic gradient is approximately equal to one-half the topographic surface gradient. The second approach used existing GIS contour files of ground water elevations from eight separate US Geological Survey watershed studies.
To determine the aquifer flow rate, the hydraulic conductivity grid layer was independently multiplied by each of the 2 hydraulic gradient grid layers. The average of the two median values from these methods (51 and 9 meters per year) was used, which gives a flow rate of 30 meters per year. See Appendix I for more details.

Infiltration Rate (I)
USEPA: no default value
NJDEP: 0.28 meters/yr (11 in/yr)

The infiltration rate corresponds to the rate of recharge of precipitation to the ground water. The infiltration rate is an input parameter for calculating a DAF. The infiltration rate was calculated for a generic sandy loam soil and a New Jersey climate using a model from the New Jersey Geological Survey. See Appendix E for more information. Infiltration rates for New Jersey soils range from about 5-17 inches per year (see Appendix E). The remediation standard is inversely proportional with respect to the infiltration rate (see Appendix B).

Source (Area of Concern) Length Parallel to Ground Water Flow (L)
USEPA default value: 45 m (148 feet)

NJDEP default value: 30 m (100 feet)

This parameter is equivalent to the length of the Area of Concern (AOC) parallel to ground water flow and is an input parameter in calculating a DAF. The Department's value results in higher remediation standards than if USEPA's value was used. The 100 feet source length was judged to be larger than most Areas of Concern in New Jersey, and therefore adequately protective. This is also approximately equal to the length of a high density residential lot size (¼ acre).

The effect of source length on the calculated remediation standard is small (see Appendix B).

Mixing Zone Depth (*d*)

USEPA: no default value

NJDEP: 3.05 m (10ft)

The mixing zone depth corresponds to the depth to which the contaminant is diluted in ground water. It is calculated from the mixing zone depth equation (Equation 4) using several other field parameters. The mixing zone depth is then used in the DAF Equation (Equation 3). Using the generic values for all of the parameters that are used in this equation, the generic mixing zone depth is calculated to be 10 feet, which is equal to the generic aquifer thickness. Sensitivity analysis was not conducted for this parameter, because its dependant parameters are incorporated in the sensitivity analysis for the DAF equation (see Appendix B).

Thickness of Affected Aquifer (d_a)

USEPA: no default value

NJDEP: 3.05 m (10 ft)

The aquifer thickness is used in calculating the aquifer mixing zone depth, which in turn is used in calculating the DAF. Since the thickness of an aquifer is highly variable, the Department selected a small value for this parameter to be protective of all aquifers that might be encountered. Ten feet was selected as an appropriate minimum thickness. Varying this parameter has little effect on the calculated remediation standard except for cases where the area of concern (AOC) length parallel to the ground water flow becomes large (see Appendix B).

<u>Dilution/Attenuation Factor (DAF)</u>

USEPA value: 20

NJDEP value: 12

Nationally, DAF values for a half-acre site have been found to vary from 1 to several thousand (USEPA, 1996b). Based on data from USEPA's SSL guidance document, the default value of 20 was judged to be inappropriate because EPA's DAF analysis indicated that it should be lower for the Atlantic coastal plain province (USEPA, 1996b). In addition, the USEPA Monte Carlo analysis uses a range of receptor well distances down gradient from the source. This is not compatible with the Ground Water Quality Standards, N.J.A.C. 7:9-6 that require compliance at the down gradient edge of the source. To determine a New Jersey-specific DAF, Equation (3) was used along with New-Jersey specific values for the various input parameters, which yielded a DAF of 12. (The values for the various input parameters have been previously discussed above.) Increasing the DAF value raises the value of the remediation standard.

<u>Avoiding redundant conservative assumptions in default parameter values</u>

In accordance with the Legislative mandate to avoid the use of redundantly conservative or unrealistic assumptions when calculating remediation standards reasonably conservative, but realistic, values and average, or typical values, are used. A table listing the approach taken for each variable is shown below. Some parameters, such as chemical properties and applicable standards, are not subject to variation, and are listed as "chemical specific". See the discussion of individual parameters above for more information.

Table 2. Extent of Conservatism in Input Parameters	
Conservative/non-conservative assumptions for Generic IGWSRS Calculations	
Parameter	*Value selected is:*
Groundwater criteria, C_{gw} (mg/L)	chemical-specific
Soil organic carbon-water partition coefficient, K_{oc} (L/kg)	chemical-specific
Soil-water partition coefficient, K_d (L/kg)	chemical-specific
Henry's law constant at 25°C, H' (dimensionless)	chemical-specific
Soil pH	conservative
Soil texture	typical
Soil porosity (v/v)	typical
Fraction organic carbon, f_{oc} (kg/kg)	typical subsurface
Water content, θ_w (L_{water}/L_{soil})	typical
Air content, θ_a (L_{air}/L_{soil})	typical
Dry soil bulk density, ρ_b (kg/L)	typical
DAF	typical
Aquifer hydraulic conductivity, K (m/yr)	typical
Gradient, i (m/m)	typical
Mixing zone depth, d (m)	conservative
Infiltration rate, I (m/yr)	typical
Length parallel to groundwater flow, L (m)	typical
Aquifer thickness, d_a *(m)*	conservative

Soil Saturation Limit (C_{sat})

Some of the generic standards listed in the USEPA SSL Guidance document are restricted by the soil saturation concentration. This concentration, which is only calculated for liquid contaminants, is the level at which non-aqueous phase liquid (NAPL) begins to form. Any contaminant present in soil above the soil saturation concentration will be present as NAPL. NAPL is not allowed to remain in soil pursuant to the Technical Requirements for Site Remediation N.J.A.C. 7:26E-6.1(d), which require that free and residual product must be treated or removed when practicable. Therefore, for liquid contaminants, the soil saturation concentration is provided as the maximum allowable remediation standard.

Only di-n-octyl phthalate had a soil saturation concentration lower than the generic IGWSRS. The generic standard for this chemical is therefore set at the soil saturation concentration. Soil saturation concentrations are shown for liquid contaminants in Appendix C.

The Impact to Ground Water Standard, as well as the Impact to Ground Water Alternate Remediation Standard (site-specific) for any contaminant may not exceed its C_{sat} value under any circumstances.

Soil Saturation Concentration Equation:

$$C_{sat} = \frac{S}{\rho_b}(K_{oc} f_{oc} \rho_b + \theta_w + H' \theta_a) \qquad \text{Equation (5)}$$

Where C_{sat} is the soil saturation concentration (mg/kg), S is the contaminant's water solubility (mg/L), and the remaining parameters are as defined above. Values for the input parameters are the same as those for Equations 1 and 2.

NAPL may also be present at concentrations lower than C_{sat} if multiple component mixtures are present. In these cases, the effective solubility of each chemical needs to be determined. A method for estimating the concentration at which residual NAPL forms for multiple component mixtures must be used (Feenstra, 1991).

Practical Quantitation Levels (PQLs)

The methods to develop chemical specific PQLS are provided in the separate rule Introduction document. A list of chemical specific PQLs is included in the Master Table of Generic Standards. In cases where the generic standard is lower than the PQL for a contaminant in soil, the remediation standard will default to the PQL.

III. Generic Impact to Ground Water Remediation Standards

Using all of the above considerations, generic Impact to Ground Water Soil Remediation Standards were developed. These are listed in Table 1 below. The Generic Soil Remediation Standards are back calculated from the health-based New Jersey Ground Water Quality Criteria, N.J.A.C. 7:9-6. The Ground Water Quality Criteria are also provided in Table 1.

Table 1. Generic Impact to Ground Water Soil Remediation Standards

Chemical	CAS Number	New Jersey Ground water Quality (health-based) Criteria(mg/L)	Generic Impact to Ground Soil Remediation Standards(mg/kg)
Acenaphthene	83-32-9	0.4	69
Acenaphthylene	208-96-8	NA[b]	NA[b]
Acetone (2-propanone)	67-64-1	0.7	1.0
Acetophenone	98-86-2	1	3.0
Acrolein	107-02-8	0.01	0.02
Acrylonitrile	107-13-1	0.00006	0.0001
Aldrin	309-00-2	0.000002	0.1
Aluminum (total)	7429-90-5	0.2	3600
Anthracene	120-12-7	2	1400
Antimony (total)	7440-36-0	0.002	1.0
Arsenic (total)	7440-38-2	0.00002	0.006
Atrazine	1912-24-9	0.003	0.03
Barium (total)	7440-39-3	2	270
Benzaldehyde	100-52-7	NA[b]	NA[b]
Benzene	71-43-2	0.0002	0.0007
Benzidine	92-87-5	0.0000002	0.0000006
Benzo(a)anthracene	56-55-3	0.00005	0.5
Benzo(a)pyrene	50-32-8	0.000005	0.1
Benzo(b)fluoranthene	205-99-2	0.00005	1.0
Benzo(ghi)perylene	191-24-2	NA[b]	NA[b]
Benzo(k)fluoranthene	207-08-9	0.0005	15
Beryllium	7440-41-7	0.000008	0.002
1,1-Biphenyl	92-52-4	0.4	83
Bis(2-chloroethyl)ether	111-44-4	0.00003	0.00007
Bis(2-chloroisopropyl)ether	108-60-1	0.3	3
Bis(2-ethylhexyl)phthalate	117-81-7	0.003	1000
Bromodichloromethane	75-27-4	0.0003	0.001
Bromoform	75-25-2	0.004	0.02
Bromomethane	74-83-9	0.01	0.02
2-Butanone (MEK)	78-93-3	0.3	0.6
Butylbenzyl phthalate	85-68-7	0.1	140
Cadmium	7440-43-9	0.004	0.7
Caprolactam	105-60-2	NA[b]	NA[b]
Carbazole	86-74-8	NA[b]	NA[b]
Carbon disulfide	75-15-0	0.8	4
Carbon tetrachloride	56-23-5	0.0004	0.003
Chlordane (alpha and gamma)	57-74-9	0.00001	0.03
4-Chloroaniline	106-47-8	0.03	0.1
Chlorobenzene	108-90-7	0.05	0.4
Chloroethane	75-00-3	NA[b]	NA[b]
Chloroform	67-66-3	0.006	0.02
Chloromethane	74-87-3	0.03	0.08
4-Chloro-3-methyl phenol	59-50-7	NA[b]	NA[b]
2-Chlorophenol	95-57-8	0.04	0.4

Chemical	CAS Number	New Jersey Ground water Quality (health-based) Criteria(mg/L)	Generic Impact to Ground Soil Remediation Standards(mg/kg)
Chrysene	218-01-9	0.005	48
Cobalt (total)	7440-48-4	NA[b]	NA[b]
Copper (total)	7440-50-8	1	5200
Cyanide	57-12-5	0.2	24
4,4'-DDD (p,p'-TDE)	72-54-8	0.0001	2
4,4'-DDE (p,p'-DDX)	72-55-9	0.0001	11
4,4'-DDT	50-29-3	0.0001	6
Dibenz(a,h)anthracene	53-70-3	0.000005	0.5
Dibenzofuran	132-64-9	NA[b]	NA[b]
Dibromochloromethane	124-48-1	0.01	0.03
1,2-Dibromo-3-chloropropane	96-12-8	0.00003	0.0001
1,2-Dibromoethane	106-93-4	0.0000004	0.000001
1,2-Dichlorobenzene	95-50-1	0.6	10
1,3-Dichlorobenzene	541-73-1	0.6	11
1,4-Dichlorobenzene	106-46-7	0.075	1
3,3'-Dichlorobenzidine	91-94-1	0.00008	0.002
Dichlorodifluoromethane	75-71-8	1	23
1,1-Dichloroethane	75-34-3	0.05	0.1
1,2-Dichloroethane	107-06-2	0.0003	0.0007
1,1-Dichloroethene	75-35-4	0.001	0.005
1,2-Dichloroethene (cis)	156-59-2	0.07	0.2
1,2-Dichloroethene (trans)	156-60-5	0.1	0.4
2,4-Dichlorophenol	120-83-2	0.02	0.1
1,2-Dichloropropane	78-87-5	0.0005	0.002
1,3-Dichloropropene(cis & trans)	542-75-6	0.0002	0.0008
Dieldrin	60-57-1	0.000002	0.001
Diethylphthalate	84-66-2	5	44
2,4-Dimethylphenol	105-67-9	0.1	0.7
Dimethylphthalate	131-11-3	NA[b]	NA[b]
Di-n-butyl phthalate	84-74-2	0.9	730
4,6-Dinitro-2-methylphenol	534-52-1	NA[b]	NA[b]
2,4-Dinitrophenol	51-28-5	0.01	0.02
2,4-Dinitrotoluene	121-14-2	0.00005	0.0002
2,6-Dinitrotoluene	606-20-2	0.00005	0.0002
Di-n-octyl phthalate	117-84-0	0.1	330(a)
1,2-Diphenylhydrazine	122-66-7	0.00004	0.0008
Endosulfan I and Endosulfan II	115-29-7	0.0004	0.02
Endosulfan sulfate	1031-07-8	0.0004	0.01
Endrin	72-20-8	0.002	0.6
Ethylbenzene	100-41-4	0.7	8
Fluoranthene	206-44-0	0.3	770
Fluorene	86-73-7	0.3	100
alpha-HCH (alpha-BHC)	319-84-6	0.000006	0.0002
beta-HCH (beta-BHC)	319-85-7	0.0002	0.006
Heptachlor	76-44-8	0.000008	0.3
Heptachlor epoxide	1024-57-3	0.000004	0.008
Hexachlorobenzene	118-74-1	0.00002	0.03

Chemical	CAS Number	New Jersey Ground water Quality (health-based) Criteria(mg/L)	Generic Impact to Ground Soil Remediation Standards(mg/kg)
Hexachloro-1,3-butadiene	87-68-3	0.001	1
Hexachlorocyclopentadiene	77-47-4	0.05	240
Hexachloroethane	67-72-1	0.0007	0.03
2-Hexanone	591-78-6	NA[b]	NA[b]
Indeno(1,2,3-cd)pyrene	193-39-5	0.00005	4
Isophorone	78-59-1	0.1	0.3
Lead (total)	7439-92-1	0.005	54
Lindane (gamma-HCH or BHC)	58-89-9	0.0002	0.006
Manganese (total)	7439-96-5	0.05	39
Mercury (total)	7439-97-6	0.002	0.006
Methoxychlor	72-43-5	0.04	94
Methyl acetate	79-20-9	7	13
Methylcyclohexane	108-87-2	NA[b]	NA[b]
Methylene chloride	75-09-2	0.003	0.007
4-Methyl-2-pentanone (MIBK)	108-10-1	0.4	0.9
2-Methylphenol (o-cresol)	95-48-7	NA[b]	NA[b]
4-Methylphenol (p-cresol)	106-44-5	NA[b]	NA[b]
MTBE (tert-butyl methyl ether)	1634-04-4	0.07	0.1
Naphthalene	91-20-3	0.3	15
Nickel (total)	7440-02-0	0.1	19
2-Nitroaniline	88-74-4	NA[b]	NA[b]
Nitrobenzene	98-95-3	0.003	0.01
4-Nitrophenol	100-02-7	NA[b]	NA[b]
N-Nitrosodimethylamine	62-75-9	0.0000007	0.000001
N-Nitrosodi-n-propylamine	621-64-7	0.000005	0.00001
N-Nitrosodiphenylamine	86-30-6	0.007	0.2
PCBs(Polychlorinated biphenyls)	1336-36-3	0.00002	0.1
Pentachlorophenol	87-86-5	0.0003	0.005
Phenanthrene	85-01-8	NA[b]	NA[b]
Phenol	108-95-2	4	10
Pyrene	129-00-0	0.2	500
Selenium (total)	7782-49-2	0.05	3
Silver (total)	7440-22-4	0.03	0.09
Styrene	100-42-5	0.1	2
Tertiary butyl alcohol (TBA)	75-65-0	0.1	0.2
1,1,2,2-Tetrachloroethane	79-34-5	0.001	0.004
Tetrachloroethene (PCE)	127-18-4	0.0004	0.003
Thallium (total)	7440-28-0	0.0005	0.3
Toluene	108-88-3	1	7
Toxaphene	8001-35-2	0.00003	0.2
1,2,4-Trichlorobenzene	120-82-1	0.009	0.4
1,1,1-Trichloroethane	71-55-6	0.03	0.2
1,1,2-Trichloroethane	79-00-5	0.003	0.009
Trichloroethene (TCE)	79-01-6	0.001	0.006
Trichlorofluoromethane (Freon 11)	75-69-4	2	21
2,4,5-Trichlorophenol	95-95-4	0.7	28
2,4,6-Trichlorophenol	88-06-2	0.003	0.03
1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	NA[b]	NA[b]

Chemical	CAS Number	New Jersey Ground water Quality (health-based) Criteria(mg/L)	Generic Impact to Ground Soil Remediation Standards(mg/kg)
Vanadium (total)	7440-62-2	NA[b]	NA[b]
Vinyl chloride	75-01-4	0.00008	0.0003
Xylenes (total)	1330-20-7	1	12
Zinc (total)	7440-66-6	5	970

(a) Standard set at soil saturation limit. Concentrations exceeding this value lead to free product, which must be removed as per the Technical Requirements for Site Remediation, N.J.A.C. 7:26E-6.1(d).

(b) No GWQC is available

IV. Alternative Remediation Standards (ARS)

Impact to Ground Water Alternative Remediation Standards (IGWARS) are based on site-specific or area-specific characteristics and data that result in more accurate values than the Department's generic remediation standards. These site-specific standards are protective of human health and the environment.

The Brownfield and Contaminated Site Remediation Act authorizes the Department to consider site-specific factors in determining appropriate remediation standards. For the Impact to Ground Water pathway the following portion of the law applies:

58:10B-12f.(1) *A person performing a remediation of contaminated real property, in lieu of using the established minimum soil remediation standard for either residential use or nonresidential use adopted by the department pursuant to subsection c. of this section, may submit to the department a request to use an alternative residential use or nonresidential use soil remediation standard. The use of an alternative soil remediation standard shall be based upon site-specific factors which may include (1) physical site characteristics which may vary from those used by the department in the development of the soil remediation standards adopted pursuant to this section… and physical characteristics of the site, including, but not limited to, climatic conditions and topographic conditions.*

IGWARS must be calculated for each Area of Concern (AOC). Input parameters specific to the AOC, such as the location of contamination, soil pH, and soil organic content can differ considerably across a site and will, in turn affect the calculation of an appropriate IGWARS.

The various options described below differ in that some of the options need no further actions, and could be classified as walk away. Other options require monitoring, (and are dependent upon the results of the monitoring being acceptable), or may require deed notices or deed restrictions.

The Department still requires that the ingestion, dermal and inhalation exposure pathways be addressed when utilizing these options.

Option A. Site-Specific Modification of the Simple Partitioning Equation

Certain input parameters in Equations (1) and (2) in Section II, Methodology for Generic IGWSRS lend themselves fairly easily to site-specific modification. The use of site data to modify generic input parameters in the Simple Partitioning Equation will generate higher alternative remediation standards that are still protective and appropriate for a given site. Some of the input parameters will have a greater effect on raising the generic standard than others. In particular, higher values for soil organic carbon content, higher ground water flow rates, and for metals, higher soil pH will have the greatest effect on raising the generic remediation standard.

The IGWARS generated by this option may result in no further action and thus would not require monitoring, deed notices or other restrictions.

The following site-specific adjustments are allowed for calculation of alternative remediation standards (ARS):

A. Modification of the fraction organic carbon, f_{oc}, value

The organic carbon content of the soil is used with a contaminant's K_{oc} value to determine the extent of adsorption to soil. In general, the soil remediation standard is linearly related to the organic carbon content. (For example, a doubling of the organic carbon content of the soil will double the calculated remediation standard.) The Lloyd Kahn method is available for determination of organic carbon content of soil (USEPA, 1988). Use of this method will be allowed to determine a sample-specific fraction organic carbon content, which may be substituted into Equation 1 to determine a sample-specific ARS.

A minimum of 3 samples, must be collected from soil types equivalent to those in the Area of Concern at depths equivalent to the location of contamination. However samples should not be from areas containing significant contamination. High levels of organic contaminants (greater than a 1,000 ppm) will contribute to an artificially high carbon content.

B. Modification of metal K_d values for soil pH

For metals, the adsorption constant (K_d) is often highly sensitive to soil pH (USEPA, 1996b). Therefore, the development of an Alternative Remediation Standard may be considered for metals for which pH-dependant K_d values are reported in the USEPA SSL document. For this option, measure the sample pH and then use the Kd associated with this pH in the simple partitioning equation. If pH varies, use the lowest resulting Kd value.

The collection of site-specific soil pH data is recommended for barium, beryllium, cadmium, mercury, nickel, silver and zinc if the soil pH is suspected to be significantly higher than 4.9.

Soil pH measurements should be determined using available standard methods. Calculate an ARS for each sample using Equation 2. A minimum of three samples representative of the AOC must be taken.

<u>For both A and B above, the following directions apply:</u>

The partitioning equation (equations 1 and 2) may be adjusted for AOC specific conditions to calculate an AOC-specific Alternative Remediation Standard. Sample-specific ARS values should be averaged together to obtain an AOC-specific ARS. If, however, calculated sample-specific ARS values vary by more than an order of magnitude, they may not be averaged to calculate an IGWARS. In this case, the lowest sample-specific ARS value must be used.

The following situations require additional soil samples be collected and submitted for testing to calculate a refined AOC-specific remediation standard:

1. The area of concern is significantly larger than the area investigated during the earlier phases of case processing. The number of samples should be based on the size of the area of concern pursuant to the Technical Requirements for Site Remediation, N.J.A.C. 7:26E.

2. Organic carbon contents and pH may vary with depth. Therefore, subsurface soil samples should be included if the contamination extends below the surface soil horizon.

C. Modification of the Dilution-Attenuation Factor (DAF)

The dilution-attenuation factor (DAF) is used in the equation for the generic remediation standard, and may be generated on a site-specific basis. Higher ground water flow rates than those assumed for calculation of the generic standard (see below) will result in ARS values that are higher than the generic remediation standards. Several parameters that are used in the calculation of the DAF (Equations 3 and 4 in Section II, Generic Methodology for IGWSRS) may be adjusted on a site-specific basis. In all cases, the length of the area of concern parallel to ground water flow, *L*, must be adjusted to reflect actual conditions. The options are modification of the following parameters:

1. Length, *L* . Although the sensitivity of the remediation standard to the size of the area of concern is small (see below), if an area of concern contains an *L* value significantly smaller than 100 feet (30.48 m), use of the site-specific value may yield an ARS slightly higher than the generic value.

2. Infiltration rate, *I*. The generic standards use an infiltration rate calculated for sandy loam soil (using the NJGS model). However, if site-specific infiltration rate data (i.e., ground water recharge data) are available, this information may be used to calculate a site-specific value for *I*. At this time, site-specific adjustment of infiltration rates is allowed only after consultation with the case team. The Department will not allow a 100% impermeable cover. For example, paving, which may result in reduced infiltration rates would not be allowed to modify the infiltration rate. If paving is used to modify the infiltration rate it would need to be included as an engineering control as part of the remedy and as such, would require a deed notice.

3. Ground water velocity parameters, (hydraulic conductivity, *K* and gradient, *i*.) Because *K* and *i* are closely linked parameters affecting ground water velocity they must be adjusted together. Site-specific estimates of the ground water Darcy velocity may be substituted into Equations (3) and (4) of Section II, Generic Methodology for IGWSRS. Such estimates must be determined from field measurements using available standard methods.

4. Aquifer thickness, d_a. This parameter influences the mixing zone depth, although its effect is minimal under the generic scenario (see below). If the actual aquifer depth for the site under investigation is known, a modified site-specific mixing zone depth, d, may be calculated.

Sensitivity of USEPA partitioning equation to variation of its input parameters

Sensitivity analyses were conducted to ascertain the effects of varying the input parameters on the calculated remediation standard. The results of the analyses are presented in Appendix B. The results are summarized as follows:

1. The following variables show a positive linear, or near-linear relationship to the calculated remediation standard: K_d, K_{oc}, ground water criteria, fraction organic carbon, DAF, hydraulic conductivity, and gradient. (That is, doubling one of these parameters will double, or approximately double, the value of the calculated remediation standard.)

2. The remediation standard is inversely related to the Infiltration rate, I. A decrease in the infiltration rate results in higher calculated remediation standards. An informal investigation of the variation of New Jersey infiltration rates as a function of soil type and climate was conducted using a ground water recharge model from the New Jersey Geological Survey (Hoffman, 1999 and Charles et al., 1996). See Appendix E for details. The investigation included land uses with 100% permeable surfaces (landscaped, bare soil, and agricultural) and soil textures ranging from sand to silt loam. The infiltration rate ranged from about 5 to 17 inches per year, with an average of 11 inches. Thus, modification of the infiltration rate alone for an Alternative Remediation Standard is not likely to result in a large change to the generic remediation standard.

3. The aquifer thickness has little effect on the remediation standard, when other parameters are held at their generic values. The utility of modifying this parameter may therefore be limited, but may be worth evaluating if the site scenario is much different from the generic scenario.

4. Changing the length of the area of concern parallel to the ground water flow, L, Henry's constant, soil moisture, soil air and soil bulk density have only a small effect on the remediation standard.

Option B. Immobile Chemicals

Chemical Characteristics and Transport Modeling Option

The Generic Impact to Ground Water Soil Remediation Standards are developed to address the potential for chemicals to be mobilized and transported to ground water. Scientific evidence suggests that chemicals become more resistant to desorption from soil as contact time increases (Loehr and Webster, 1996; Alexander, 1995; Pavlostathis and Mathavan, 1992). Highly adsorbed chemicals, such as chlorinated pesticides, may become irreversibly adsorbed to soil and therefore immobile (Alexander, 1995). This behavior would be added to the already low transport potential of these contaminants (due to their high soil adsorption coefficients). Therefore, it can be assumed that these chemicals do not pose a threat to ground water if an adequate zone of clean soil exists between the contamination and the ground water.

To determine an acceptable thickness for the clean soil zone, transport simulations are run using the SESOIL model. Simulations are conducted for a 100-year time period. This time period was selected because transport is not likely after this length of time since these chemicals would become irreversibly adsorbed. (The time period for reduced desorption to occur has been reported to be on the order of weeks or months for several chemicals (Loehr and Webster, 1996; Alexander, 1995; Pavlostathis and Mathavan, 1992)).

Simulation results indicated that chemicals with K_{oc} values greater than or equal to 50,000 ml/gm (or K_d value of greater than 100 ml/gm) moved vertically 11 inches or less during the 100 year simulation period (Appendix F). The following chemicals behaved3 in this manner:

Aluminum
Copper
Lead
Vanadium
Aldrin
Benzo(a)anthracene
Benzo(a)pyrene
Benzo(b)fluoranthene
Benzo(ghi)perylene
Benzo(k)fluoranthene
Bis(2-ethylhexyl phthalate)

Butyl benzyl phthalate
Di-n-butyl phthalate
Chlordane
Chrysene
DDD
DDE
DDT
Dibenz(a,h)anthracene
Di-n-octyl phthalate
Fluoranthene
Heptachlor
Hepachlor epoxide
Hexachlorobenzene
Hexachloro-1,3-butadiene
Hexachlorocyclopentadiene
Indeno(1,2,3-cd)pyrene
Methoxychlor
PCBs
Pyrene
Toxaphene

The Department has determined that the chemicals on the above list do not require remediation to the Generic Impact to Ground Water Soil Remediation Standard, provided that all of the following conditions are accounted for:

- A 2 foot zone of uncontaminated (less than or equal to the generic standard) soil exists between the contaminants and the seasonally high water table;

- Co-solvency effects: Some compounds have capabilities of solubilizing other chemicals. If there are co-solvents present that may mobilize chemicals on the above list, the option would not apply;

- Types of soil: The SESOIL simulations are conducted utilizing a sandy loam soil. If the soil texture differs substantially from a sandy loam (for example, if site soils are classified as sands), this option will require site-specific evaluation and pre-approval by the Department. Pursuant to N.J.A.C. 7:26E-6.1(d) this option is not applicable to free, or residual product. In addition, this option is not applicable to contaminants in fill. Fill is a heterogeneous mixture of different materials to which the SESOIL model does not apply; and

- Soil pH: If soil pH has been altered due to anthropogenic activities, discharges of acids or bases, etc., this option cannot be used.

The IGWARS generated by this option may result in no further action, thus would not require monitoring, deed notices or other restrictions.

Option C. Synthetic Precipitation Leaching Procedure

Introduction

The Synthetic Precipitation Leaching Procedure (SPLP) is an EPA SW-846 analytical method (Method 1312) that can be used to determine the concentration of contaminant that will leach from soil (USEPA, 1998). The results of this procedure can be used directly to determine an AOC specific impact to ground water standard, or may be used indirectly to determine an AOC specific adsorption constant (K_d). This K_d value may then be substituted into the simple partitioning equation to calculate a sample-specific impact to ground water remediation standard. SPLP offers a quick and inexpensive method to develop site-specific alternative remediation standards for inorganic, semi-volatile and pesticide contaminants that will be protective of ground water.

A particularly useful aspect of the SPLP procedure is that it measures desorption, rather than adsorption, of contaminants from soil. It is well known that adsorption of many chemicals to soil increases as contact time increases (Loehr and Webster, 1996; Alexander, 1995; Pavlostathis and Mathavan, 1992). This is particularly true for less mobile contaminants. In some cases, contaminants may become irreversibly adsorbed to soil and therefore immobile. Soil adsorption coefficients (and K_{oc} values) used in the USEPA SSL partitioning equation do not consider these processes. While the USEPA partitioning equation could be used with desorption, rather than adsorption coefficients, values for desorption coefficients are not generally available and if they are available they are likely to be site-specific. Therefore, generic standards are determined using adsorption coefficients and are therefore often conservative.

Because the SPLP procedure uses the soil on site, it addresses species-specific issues regarding inorganic contaminants, particularly metals. The USEPA's simple partitioning equation assumes the most mobile form of an inorganic contaminant to estimate an adsorption coefficient for use in the partitioning equation (USEPA, 1996b). Because the actual species (redox state, salt, or complex) of an inorganic contaminant at a discharge site is typically not known after the site investigation phase, this assumption is necessary for generic analysis in order to be adequately protective of all situations that may occur. The SPLP procedure, on the other hand, measures the leaching potential of the actual species of the contaminant present at the discharge site. Different species of metals can have widely varying mobility. Speciation is generally not known because standard analytical methods usually measure total metals only. The SPLP test will measure the actual mobility, regardless of species. While a detailed assessment of the results of this test may be complex when mixtures of different species of the same metal are present, the procedure nonetheless provides a much-improved estimate of leaching tendency relative to the generic level assumptions.

The conditions of the SPLP test simulate actual environmental precipitation, in that the leaching solution is a simulation of mid-Atlantic rainfall (pH 4.2). Thus, the test more realistically estimates the leaching potential of contaminants that may occur under field conditions in New Jersey (Brown et al., 1996; Lackovic et al., 1997). Because the leaching test is conducted with actual soil samples taken from the site, remediation standards developed using this test are expected to be much more representative of site conditions than standards determined via other methods.

The utility of SPLP for case processing can be significant. SPLP can be easily and quickly conducted on samples during the site investigation in a time and cost efficient manner.

For all of the reasons above, it is recommended that the SPLP ARS option be used during the site investigation (SI) for cases involving semi-volatile chemical, pesticide and inorganic contaminants. The processing of these cases is likely to be considerably accelerated when SPLP results are available.

The limitations of the SPLP test are as follows. First, because leachate is filtered through a 0.6 - 0.8 μm filter, the concentration of colloidal metals above this pore size may be underestimated. Second, because the oxidation/reduction potential of the sample is not preserved when the test is conducted, the interconversion of metal species with multiple oxidation states may occur. Third, at this time the Department is not allowing the use of the SPLP procedure to determine the leaching potential of volatile organic compounds. The Department requires that volatile organic soil samples be collected using either methanol preservation or the Encore® sampler. Methanol cannot be added to an SPLP sample because it affects contaminant desorption. The Encore®

sampler comes in 5 or 25 gram sizes, which would require the collection of several samples to achieve the required sample size for the SPLP test and total soil analysis. These separate samples would need to be composited, which is difficult without loss of volatiles. Furthermore, volatiles are weakly adsorbed to soil, so the use of the SPLP test will usually not significantly increase the calculated standard.

The IGWARS generated by this option may result in no further action, thus would not require monitoring, deed notices or other restrictions.

Sampling procedures required for SPLP

When using SPLP during the investigation of an AOC, the number of samples collected should be determined by the size of the area initially being investigated pursuant to the Department's Technical Requirements for Site Remediation, N.J.A.C. 7:26E. At a minimum, three samples must be taken per AOC. Ideally, the samples must be chosen to target the highest concentrations of the chemicals. Furthermore, the samples should be representative of the variation in soil conditions over the area of concern, including variation with soil depth.

Samples taken for SPLP analysis must be split, because the calculation of a site-specific remediation standard, or a site-specific K_d value requires knowledge of the total contaminant concentration in the soil sample. One sample must be analyzed for total contaminant concentration, and the other for SPLP analysis. When reporting SPLP results, the total contaminant concentration in the soil, the leachate concentration, and the pH of leachate must be reported.

The following situations (not inclusive) may require that additional soil samples be collected for SPLP testing to refine an AOC specific IGWARS:

1. Contamination extends to a depth not investigated during Site Investigation. Because soil properties often vary with depth, subsurface soil samples should be included if the contamination extends below the surface soil.

2. Contaminant concentrations measured during the Remedial Investigation are found to be higher than those measured during the Site Investigation.

Using SPLP Results

1. Pass/Fail

This option was developed for cases where all SPLP leachate results are below a "Target Ground Water Concentration" or the Practical Quantitation Limit (PQL), as specified in the Department's GWQS N.J.A.C. 7:9-6. The target ground water concentration, (TGWC) is the Ground Water Quality Criterion pursuant to N.J.A.C. 7:9-6 *et seq.* multiplied by the generic DAF of 12.

Therefore, if all SPLP samples taken from an area of concern yield leachate concentrations that are below the higher of the TGWC or the PQL, no remediation of the soil is necessary for the impact to ground water exposure pathway for that specific AOC. See examples below:

To determine if further remediation is needed, compare SPLP results with the PQL and the TGWC, which is the Ground Water Quality Criterion that has been multiplied by the generic DAF of 12. If all SPLP results are lower than the PQL and the GWQC x 12 then no further remediation of the soil is necessary for the impact to ground water exposure pathway. This analysis should be done for each AOC. See examples below:

Chemical	GWQC	TGWC (GWQC*DAF)	PQL
Lead	5 μg/L	60 μg/L	10 μg/L
Toxaphene	0.03 μg/L	0.36 μg/L	3 μg/L

Target Ground Water Concentration (*TGWC*) = the Ground Water Quality Criteria (GWQC) unadjusted for PQLs x the DAF

GWQC = Ground Water Quality Criterion from N.J.A.C. 7:9-6

DAF = Dilution-attenuation factor (default DAF=12)

PQL = Practical Quantitation Levels from N.J.A.C. 7:9-6

For the chemical lead, the TGWC is 60 ug/L (GWQC of 5 μg/L multiplied by the generic DAF,12). According to the Department's Ground Water Quality Standards, the PQL for lead is 10 μg/L. The calculated TGWC is higher than the PQL; therefore, if the leachate concentrations from the SPLP tests are less than the TGWC of 60 μg/L, soil remediation for lead is not necessary for this exposure pathway.

For the chemical toxaphene, the TGWC is 0.36 μg/L. According to the Department's Ground Water Quality Standards, the PQL for toxaphene is 3 μg/L. The calculated TGWC is lower than the PQL; therefore, if the leachate concentrations from the SPLP tests are less than the PQL of 3 μg/L, soil remediation for toxaphene is not necessary for this exposure pathway.

If some or all samples yield leachate concentrations above the TGWC or PQL, continue to Option 2 or 3 below.

NOTE: In cases where contaminants are weakly adsorbed to soil, an adjustment to the SPLP leachate concentration may be necessary (see section "Adjustment of leachate concentration for weakly adsorbed chemicals" below).

<u>2. Procedure when SPLP results vary by more than an order of magnitude, or when SPLP results are above the TGWC/PQL</u>

This option allows the user to develop an IGWARS by identifying the highest soil concentration at which all leachate concentrations when divided by the DAF are at or below the GWQC.

The SPLP leachate results represent the concentration of contaminant in soil pore water before dilution by the saturated zone. Therefore, the SPLP leachate concentration is divided by the DAF (12) to represent the instantaneous dilution of contamination as it enters the saturated zone. The soil concentration may be used as an IGWARS.

$$\frac{C_L}{DAF} \leq GWQC$$

To develop an IGWARS using this option divide all SPLP leachate concentrations by the DAF (12) and compare the resulting numbers to the GWQC. The examples below illustrate this approach:

Example 1.

C_T(mg/kg)	C_L(μg/L)	C_L/DAF	GWQC (μg/L)
5	900	75	200
10	1200	100	200
30	2280	190	200
50	1680	140	200
75	2700	225	200

where:

C_L = Concentration of contaminant in the SPLP leachate (μg/L)

DAF = Dilution attenuation factor (default DAF=12)

GWQC = the Ground Water Quality Criterion, N.J.A.C. 7:9-6

C_T = the total concentration of the contaminant in the SPLP soil sample (mg/kg)

In the example above, the GWQC for the chemical of concern is 200 μg/L, the IGWARS would be 50 mg/kg because it is the highest soil concentration at which all leachate concentrations when divided by the DAF are at or below the GWQC.

Example 2.

C_T(mg/kg)	C_L(μg/L)	C_L/DAF	GWQC (μg/L)
5	900	75	150
10	1200	100	150
30	2280	190	150
50	1680	140	150
75	2700	225	150

where:

C_L = the concentration of contaminant in the SPLP leachate (μg/L)

DAF = the dilution attenuation factor (default DAF=12)

GWQC = the Ground Water Quality Criterion, N.J.A.C. 7:9-6

C_T = the total concentration of the contaminant in the SPLP soil sample (mg/kg)

In the example above, the GWQC for the chemical of concern is 150 μg/L, the acceptable IGWARS would be 10 ppm. Although the sample with a total concentration of 50 mg/kg yields an acceptable leachate result, the 30 ppm sample does not, and the IGWARS would default to the highest soil concentration at which all leachate concentrations when divided by the DAF are at or below the GWQC, in this case 10 mg/kg.

NOTE: In cases where contaminants are weakly adsorbed to soil, an adjustment to the SPLP leachate concentration may be necessary (see section "Adjustment of leachate concentration for weakly adsorbed chemicals" below).

3. Calculate Sample-Specific Alternative Remediation Standard

A sample-specific IGWARS may be calculated using the total contaminant concentration in a soil sample (C_T), and the SPLP leachate concentration (C_L). These results and other sample specific data are used to calculate a sample-specific soil-water partition coefficient (K_d), which is then substituted into the USEPA simple partitioning equation. See below:

Step 1. Calculate Sample Specific K_d

For each sample where the SPLP leachate concentration is above the Minimum Detection Limit (MDL), calculate a K_d value using the formula below:

$$Kd = \left[\frac{(C_T M_S - C_L V_L)/M_S}{C_L} \right] \qquad \text{Equation (6)}$$

The equation is derived in Appendix H, where:

K_d = soil water partition coefficient (L/kg)

C_T = the total concentration of the contaminant in the SPLP soil sample (mg/kg)

M_S = the total weight of the soil sample submitted for SPLP analysis (kg)

C_L = the concentration of contaminant in the SPLP leachate (mg/L)

V_L = the volume of the SPLP leachate (L)

If the K_d values vary by less than an order of magnitude, the results may be averaged and this average substituted into the simple partitioning equation.

If the K_d values vary by more than an order of magnitude, they may not be averaged. In this case, the lowest calculated K_d value may be used in the simple partitioning equation.

Step 2. Substitute Sample Specific K_d values in the Simple Partitioning Equation

Calculate the IGWARS for the impact to ground water pathway using the following equation:

Simple Partitioning Equation:

where:

$$ARS = C_{gw}\left\{\left[K_d\right] + \frac{\theta_w + \theta_a H'}{\rho_b}\right\}DAF$$

ARS = alternative remediation standard (mg/kg)

$\boldsymbol{K_d}$ = is the average, or lowest, calculated sample specific soil-water partition coefficient (L/kg)

$\boldsymbol{\theta_w}$ = the volume fraction of water in the original soil sample (v/v, assume generic value of 0.23 unless site-specific data indicates otherwise)

$\boldsymbol{\theta_a}$ = the volume fraction of air in the original water sample (v/v, assume generic value of 0.18 unless site-specific data indicates otherwise)

H' = the dimensionless Henry's law constant for the contaminant of interest

$\boldsymbol{\rho_b}$ = the dry bulk density of the soil (1.5 kg/L)

DAF = the dilution-attenuation factor (default DAF = 12)

$\boldsymbol{C_{gw}}$ = the ground water criteria for the contaminant (mg/L)

4. Use of Regression analysis to calculate IGWARS using results from the Synthetic Precipitation Leaching Procedure

If an adequate linear correlation is observed between observed leachate concentrations and their corresponding total soil concentrations, a linear regression technique may be used to determine the acceptable total soil concentration.

1. Plot the leachate concentration versus total soil concentration for all samples where both concentrations are above the detection limit. The x-axis (independent variable) is the total soil concentration and the y-axis (dependent variable) is the leachate concentration.

2. At least half of the points must lie at or above the midpoint of the range of total soil concentrations, and the Target Ground Water Concentration (TGWC) must lie within the range of measured leachate concentrations.
3. Do a linear least-squares regression analysis of the plotted points. If the R-square value is 0.8 or higher, the calculated linear regression line may be used to determine the acceptable total soil concentration.
4. Calculate the acceptable total soil concentration:

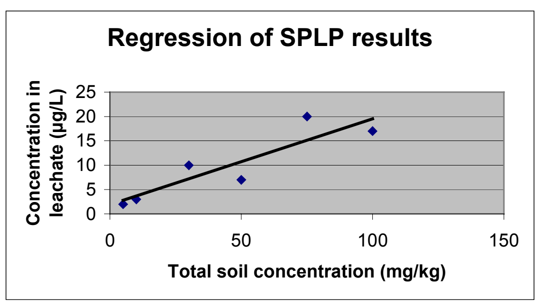
$$IGWARS = \frac{TGWC - b}{m}$$

where IGWARS is the impact-to-ground water alternative remediation standard, TGWC is the target ground water concentration, and *m* and *b* are the slope and intercept of the best fit line obtained via linear regression.

NOTE: For cases where contaminants are weakly adsorbed to soil, an adjustment to the SPLP leachate concentration may be necessary (see below).

Example Linear Regression and Calculations

Total soil concentration (mg/kg)	Leachate concentration (µg/L)
5	2
10	3
30	10
50	7
75	20
100	17



EXCEL REGRESSION OUTPUT

Regression Statistics		
Multiple R	0.896947203	
R Square	**0.804514286**	**Acceptable**
Adjusted R Square	0.755642857	
Standard Error	3.638133025	
Observations	6	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	217.8892857	217.8893	16.46185	0.015382614
Residual	4	52.94404762	13.23601		
Total	5	270.8333333			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept (b)	**1.894047619**	2.456621896	0.770997	0.483724	-4.926642348	8.714738	-4.926642348	8.714737586
X Variable 1(m)	**0.176428571**	0.043484007	4.057321	0.015383	0.055697364	0.29716	0.055697364	0.297159779

If Target Groundwater Concentration (TGWC) is 10µg/L,
then

IGWARS = (10µg/L - 1.89µg/L)/0.176(µg/L)/(mg/kg) = **46 mg/kg**

Adjustment of leachate concentration for weakly adsorbed chemicals

Normally, contaminants subjected to the SPLP tests are highly adsorbed to the soil. For hazardous waste sites that have existed for many years, contaminants that are weakly adsorbed have already migrated away from the site.

In cases where discharges are recent or very large in size, contaminants may still be relatively mobile (i.e., weakly adsorbed to soil) at the time of the Site Investigation. In these situations, the leachate concentration determined using the SPLP test may underestimate concentrations that would be observed under natural conditions because the large amount of extracting solution used dilutes the contaminant. The ratio of extracting solution weight to the soil weight employed in the SPLP test is 20 to 1. In contrast, a representative soil water to soil solids ratio in saturated sandy loam soil in New Jersey (the field conditions under which leaching would occur) is approximately 0.41 ml moisture to 1.5 grams of soil. The dilution error in the SPLP test becomes significant when approximately 25% of the contaminant is found in the leachate solution, or when the K_d is less than or equal to 50 L/kg:

Leachate concentration (mg/L) as a function of leaching volume			
Kd (L/kg)	Natural conditions 0.41mL water per 1.5gram of soil	SPLP conditions (20mL extractant per gram of soil)	% of contaminant in leachate
1	11.6	0.64	96
10	1.3	0.44	66
20	0.66	0.33	50
20	0.66	0.33	50
50	0.27	0.19	28
100	0.13	0.11	16
Total contaminant concentration (dry soil basis):13.3mg/kg			

Note that when K_d is less than 50 L/kg, the difference between the SPLP concentration and the natural field leachate concentration becomes significant.

For this reason, when using Options 1, 2, and 4, the total mass of contaminant in the leachate should be compared to the total mass of contaminant in the soil sample. When the mass of contaminant in the leachate exceeds 25% of the total mass, an adjustment of the leachate concentration is necessary.

Equation to check % of contaminant in the leachate:

$$(C_L \text{ x } V_L)/(C_T \text{ x } M_S) \text{ x } 100 \qquad \text{This should be less than 25.}$$

Where V_L is the volume of leachate in liters (often 2 L), M_S is the mass of the soil sample in kilograms (often 0.1 kg), and C_L and C_T are the leachate concentration (mg/L) and the total soil concentration (mg/kg), respectively.

When a leachate concentration adjustment is necessary, a K_d is first calculated for the chemical for each sample using Equation (6) under Option 3:

$$Kd = \left[\frac{(C_T M_S - C_L V_L)/M_S}{C_L}\right]$$

where:

$\boldsymbol{K_d}$ = is the soil water partition coefficient (L/kg)
$\boldsymbol{C_T}$ = the total concentration of the contaminant in the SPLP soil sample (mg/kg)
$\boldsymbol{M_S}$ = the total weight of the soil sample submitted for SPLP analysis (kg)
$\boldsymbol{C_L}$ = the concentration of contaminant in the SPLP leachate (mg/L)

$\boldsymbol{V}_{\mathbf{L}}$ = the volume of the SPLP leachate (L)

This K_d value is then substituted in the following equation, which is a simple rearrangement of the USEPA simple partitioning equation (no air phase):

$$C_{adj} = C_T[\rho_b/(K_d \text{ x } \rho_b \text{ x } \theta_w)]$$

Where ρ_b is the bulk density of the soil (1.5 kg/L), and θ_w is the soil moisture (0.23), and C_{adj} is the adjusted leachate concentration (mg/L).

Option D. SESOIL Transport Modeling when Ground Water Has Not Yet Been Impacted

Introduction

The Department allows the use of the SESOIL unsaturated zone transport model for determination of an AOC-specific IGWARS when a clean zone of soil exists between the contamination and the water table. The SESOIL model may be useful in cases where the contaminant has low mobility, or has a higher mobility but is either present at low levels or has a low toxicity. If the contaminant has low mobility the contaminant will not migrate to the water table even under long simulation times. If the contaminant is present at low concentrations or has a low toxicity then the contaminant may reach the water table, but concentrations in the ground water may meet the health based GWQC. See Appendix G for background information on the SESOIL model.

While the original SESOIL code is available free of charge from the USEPA, it lacks a user interface. Commercially available software packages contain both the source code and interfaces to assist users in the selection and preparation of input data and for viewing and presenting model output.

For use on New Jersey contaminated sites, the Department has assigned default input parameter values. When adjusting the default scenario for site-specific purposes, the Department has set restrictions on how the model may be used, what input parameters may be changed, and what restrictions are imposed on their modification. Guidance on the use of SESOIL and restrictions on the various input parameters may be obtained from the case team.

In cases where ground water has not yet been contaminated, the Department policy is to maintain the ground water quality and avoid future ground water contamination. The SESOIL model may be used to determine whether current levels of soil contamination may impact the ground water in the future. SESOIL may also be used to calculate a site-specific remediation standard that will not result in future ground water impacts above the ground water criteria.

The IGWARS generated by this option may result in no further action, thus would not require monitoring, deed notices or other restrictions.

Procedure

To calculate an AOC-specific remediation standard using this option, a target ground water concentration is first calculated by multiplying the GWQC by the DAF (12). The SESOIL model is then used to calculate a contaminant leachate concentration just above the water table, which is compared to the target ground water concentration. By comparing this predicted concentration to the target ground water concentration, an acceptable soil remediation standard may then be back calculated.

<u>Step 1: Run SESOIL with AOC-specific parameters</u>

Consult the case team for details on determining site-specific input. In general, the following guidelines must be followed:

1. Generic soil properties for sandy loam, loam or silty clay loam soil must be entered, whichever is appropriate. Organic carbon content should be set at 0.2% unless site information is available.
2. Climate data from the station nearest the site should be used.
3. Evaluate soil layers in 1foot increments.
4. Generic chemical properties for contaminants may not be changed. A 1-month half-life may be used as a degradation rate for benzene, toluene, ethylbenzene and xylene provided that aerobic conditions can be demonstrated in the vadose zone; otherwise, no degradation is allowed unless site-specific and contaminant-specific information is available.
5. Enter the size of area of concern.
6. Contaminant concentrations (either existing or proposed remediation standards) must be entered as initial concentrations in the appropriate soil layers.
7. Run time should be set to 100 years for low mobility contaminants. For mobile contaminants, the model should be run long enough to achieve peak concentrations in the ground water.
8. The time-dependant concentration of the contaminant in the soil moisture in the deepest soil layer is compared to the Target Ground Water Concentration (*TGWC*) to determine

compliance with ground water criteria. (*TGWC* = the Ground Water Quality Criteria (GWQC) *unadjusted* for PQLs x the DAF).

Step 2: Determine if predicted ground water concentrations are acceptable

Acceptable ground water conditions are illustrated in Figures 1 and 2. For mobile contaminants, the peak predicted concentration should not exceed the Target Ground Water Concentration (Figure 1). For contaminants that are immobile or exhibit low mobility, the Department has decided that protection of the ground water for 100 years is satisfactory. The reasoning behind this decision is explained in the discussion of immobile contaminants (see Option B above). When using this ground water condition, SESOIL results should indicate a ground water concentration that does not exceed the *TGWC* for at least 100 years (Figure 2).

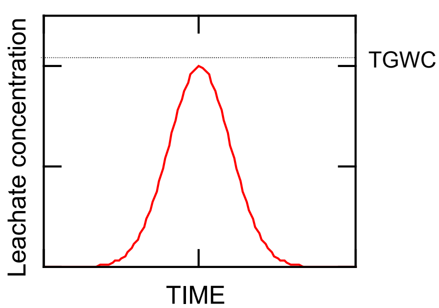


Figure 1

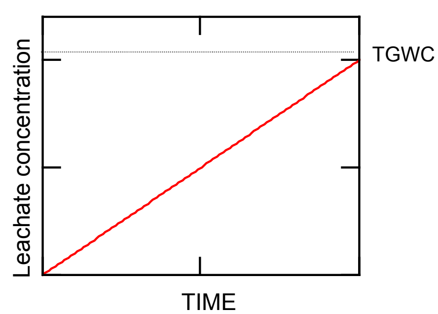


Figure 2

If the Target Ground Water Concentration is not exceeded by the predicted ground water concentration, the soil concentrations simulated are acceptable. If these are the current soil concentrations, no further remediation is necessary.

If the Target Ground Water Concentration is exceeded by the predicted ground water concentrations, the soil concentrations simulated are too high and remediation is required.

STEP 3: Use SESOIL to calculate AOC-specific remediation standard

The model should be rerun with a lower soil concentration so that acceptable ground water conditions result. Typically, a linear adjustment of the initial soil concentration will yield acceptable results. The SESOIL modeled soil concentration that results in a ground water concentration equal to the target ground water concentration should be used as the soil remediation standard.

Option E. Vadose Zone /Ground Water Modeling (Sesoil/At123d)

Introduction

AT123D is an analytical “three dimensional” ground water contaminant transport model originally developed by YEH G.T (1981). The model computes the spatial-temporal concentration distribution of contaminants in an aquifer system and predicts the transient spread of a contaminant plume through the aquifer (See Appendix G). The SESOIL/AT123D coupled model may be used to derive a restricted alternative remediation standard based on the conditions below:

1. Ground water is presently contaminated by the contaminated soil at the AOC;

2. Ground water contamination has been delineated;

3. A natural ground water remediation or active ground water remediation is approved by the Department in accordance with the requirements of N.J.A.C. 7:26E-6.3(d) and a ground water classification exception area is established as part of the remedy;

4. Ground water is not currently used for potable purposes and there are no plans to use it based on a 25-year planning horizon as projected by local and county land use documents. This shall include, without limitation, information pertaining to the existence of water lines, proposed future installation of water lines, local and/or county ordinances restricting installation of potable wells; and

5. There is no potential for contaminated ground water to impact any receptor (including but not limited to potable wells, surface water, wetlands or indoor air quality).

Acceptable Ground Water Contaminant Plume Conditions

The SESOIL/AT123D model simulates future impacts to ground water from specified soil contamination conditions. To develop a restricted alternative remediation standard the model is used in a trial and error fashion to calculate an acceptable soil concentration for certain acceptable ground water contaminant plume conditions. The modeled ground water contaminant plume must meet the following conditions:

1. Concentrations of contaminants at the modeled source area must meet the target ground water concentration in five years or less; and

2. The AT123D predicted plume shall not extend further than the delineated extent of the ground water contamination plume.

Using SESOIL/AT123D to Determine AOC Specific ARS

First, use the SESOIL model to generate the contaminant source input for the AT123D model. Many of the input parameters for the AT123D model are copied from SESOIL files. For guidance on the remaining parameters, consult the case team.

Vary the concentration of soil contamination in the SESOIL/AT123D to determine the Impact to Ground Water soil remediation standard such that the predicted maximum extent of ground water contamination is less than or equal to the acceptable plume condition given above.

Ground Water Monitoring Requirements

Ground water monitoring will be required when this option is used. Predictions made by the SESOIL AT123D must be confirmed by ground water monitoring. Additional remediation will be required if ground monitoring does not agree with model predictions.

Option F. Consideration of Observed Ground Water Conditions

Alternative remediation standards may be determined based on current ground water conditions and other site-specific factors. Approval from the Department for this alternative remediation standard results in no further action, and does not require additional monitoring, deed notices or other restrictions.

If the highest concentration of soil contamination is present at the seasonally low water table and no impact to ground water is observed, no remediation for the impact to ground water pathway is required. Pertinent site conditions include the age of the discharge and the location of the highest soil contamination. **G**round water sampling results may be used to determine if soil contamination is immobilized and poses no threat to ground water quality provided:

- Delineation has been conducted to demonstrate the highest concentration of soil contamination is located at the seasonally low water table; and

- A minimum of two ground water samples, biased to the highest soil sample locations, must be collected. The samples shall be collected no sooner than thirty days apart and must demonstrate that there is no ground water impact.

In this instance, soil identified as exceeding the generic Impact to Ground Water Soil Remediation Standards (IGWSRS) does not require remediation for the impact to ground water pathway.

V. Compliance

Ground water classification

The ground water standard is dependent on the classification of the ground water under the site. There are three primary ground water classifications established by the Ground Water Quality Standards N.J.A.C. 7:9-6:

1. Class I Ground Water of Special Ecological Significance
2. Class II Ground Water for Potable Water Supply
3. Class III Ground Water With Uses Other Than Potable Water Supply

Class I

The Ground Water Quality Standards (N.J.A.C. 7:9-6.7(a)) establish ground water quality criteria for Class I areas as the natural quality for each constituent and is a nondegradation classification where natural quality shall be maintained or restored. Because the generic IGWSRS are developed to be protective of Class II ground water standards, they are not appropriate for areas of Class I ground water. In Class I areas ground water contaminants must be remediated to background quality. Therefore, IGW standards for soil must be developed on a site-specific basis and submitted to the Department for approval.

Class II

The Ground Water Quality Criteria for Class II are listed in Table 1 of the Ground Water Quality Standards, N.J.A.C. 7:9. These criteria and interim specific criteria are developed specifically for Class II ground water and are protective of potable water use. The generic impact to ground water soil remediation standards and site specific alternative soil remediation standards are developed to be used in Class II-A ground water areas.

Class III

Class III ground water is not suitable for potable use due to natural hydrogeologic characteristics or natural water quality. The Ground Water Quality Standards do not contain numeric constituent standards or precise boundaries for these ground waters. Constituent standards must be developed on a site-specific basis with consideration of potential impacts to surface water, wetlands, subsurface and interior vapors and adjacent ground water with a higher classification. Once site-specific GWQC are developed for Class III ground water, a site-specific IGWARS must be developed by back calculating from the GWQC to an appropriate soil number.

Compliance Sampling

To ensure that contamination in soil will not result in any exceedance of ground water quality criteria the Department requires sample by sample compliance for the impact to ground water pathway. Therefore, averaging of sample results at a site or within an area of concern is not acceptable.

Monitored Natural Attenuation of Soils Contaminated with Petroleum Hydrocarbons and Gasoline Additives

Sites contaminated with petroleum hydrocarbons may be remediated using natural remediation because many components of petroleum contamination can intrinsically biodegrade in aerobic aquifer environments that predominate in New Jersey (McLaughlin, 1996), (McLelland, 1996). Assessing ground water contaminant levels can provide adequate information on the degradation of petroleum hydrocarbon contamination in the soils. However, certain gasoline additives, such as methyl tertiary butyl ether (MTBE) and tertiary butyl alcohol (TBA) may not readily biodegrade. These compounds also do not readily adsorb onto the soil and instead, due to their higher solubility, move rapidly through the unsaturated zone, and dissolve into the ground water. Therefore, since MTBE and TBA tend to migrate downward and dissolve directly into the ground water, assessing the ground water contaminant concentration trends can provide adequate information on the impacts of soil contamination on the ground water quality.

In cases where it is impracticable to completely remove petroleum contaminated soils to meet the generic Impact to Ground Water Soil Remediation Standards (IGWSRS) and/or the residual contaminant mass in the soil is not adversely impacting the ground water, the existing concentrations of soil contamination may not require further remediation and may be determined to be in compliance with this pathway provided **all** of the following conditions are met:

- There are no receptors, as defined in N.J.A.C. 7:26E-1.8 that can be impacted by the contaminated ground water or soil;

- All soil contamination must be delineated in accordance with N.J.A.C. 7:26E-4.1 to the generic Impact to Ground Water Soil Remediation Standards. In addition, if soil remediation has occurred (i.e soil excavation), the generic IGWSRS are the end point that will be used to evaluate the post-excavation sampling results and the need for additional soil delineation;

- All free and residual product has been remediated in accordance with N.J.A.C. 7:26E-6.1(d);

- The highest level of soil contamination is located within the range of monitored ground water elevation fluctuations;

- It is impracticable to remove the remaining contaminated soils;

- A Department approved ground water monitoring program that meets the requirements of N.J.A.C. 7:26E-6.3(e) has been implemented at the site. In addition, a decreasing trend in contaminant concentrations shall be established through all rise and falls in the water table elevations, thus showing that there is no correlation between the water table elevation and contaminant concentration (i.e. the ground water concentrations increase when the water table elevation drops). Ground water quality data and the need for additional soil remediation shall be evaluated pursuant to N.J.A.C. 7:26E-6.3(e)3; and

- If a decreasing trend in ground water concentrations can not be demonstrated or there is a threat to any receptor, then additional remediation of the remaining soil contamination is required.

Following the appropriate ground water sampling to demonstrate decreasing trends, a proposal for no further action may be evaluated and approved, provided all the criteria in this compliance option are met. If the concentrations of contaminants in ground water still exceed the Ground Water Quality Standards (GWQS) at the time of the NFA request, the case will not receive an unrestricted use no further action. The case will be closed with a Classification Exception Area (institutional control) and the responsible party will be required to sample the ground water pursuant to N.J.A.C. 7:26E-8.6(a)7i within 120 calendar days after the projected expiration date of the CEA to confirm compliance with the requirements of N.J.A.C. 7:26E-8.6(a)7 *et seq*.

The Department will evaluate all proposals using this compliance option and determine if the criteria for compliance have been met. Proposals should include any claims of the impracticality of removing any remaining contaminated soils. In addition, as stated above, if a decreasing trend in ground water concentrations can not be demonstrated or there is a threat to any receptor, then additional remediation of the residual soil contamination is required.

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VII. APPENDICES

APPENDIX A
Federal Standards Analysis

Executive Order No. 27 (1994) and N.J.S.A. 52:14B-1 et seq. (P.L. 1995, c.65) require State agencies which adopt, readopt or amend State regulations that exceed any Federal standards or requirements to include in the rulemaking document a comparison with Federal law. The USEPA has not promulgated soil standards but has developed Soil Screening Levels, which are provided as guidance.

The Department used EPA guidance to develop the generic impact to ground water remediation standards to the greatest extent possible. However, the Department's standards for beta-HCH (beta-BHC) and 1,1,2,2-tetrachloroethane are higher than the federal screening levels. This is because New Jersey's ground water criteria are higher than the corresponding federal criteria (MCLGs, MCLs or HBLs).

For the remaining chemicals, the two tables below list chemicals for which no federal screening levels exist (Table 1), and chemicals for which the Department standards are lower than federal screening levels (Table 2).   Table 2 indicates, for each parameter, the reason why the Department standard is more stringent than the federal screening level. In all cases, the Dilution-Attenuation Factor (DAF*)* of 12 is applied to New Jersey standard, while USEPA uses a default DAF of 20.

This difference results in the Department's standards being reduced by almost a factor of two relative to the federal screening levels. This is indicated by the "DAF" code in the right column in Table 2. For the majority of contaminants, an even larger reduction in the standard results from the value of the Department's ground water quality criteria relative to the federal ground water screening level. The Department's groundwater quality criteria are usually lower, and sometimes substantially lower. The differences in the ground water criteria between the two agencies are often attributable to either differences in the toxicological endpoint or assessment, or to the fact that the Department's values used are always health-based, while the federal values are sometimes limited by analytical detection limits or treatment capabilities. Refer to the documentation for the applicable programs for further information. Chemicals affected by this parameter are indicated with "GW" in the right column. These two factors explain the primary differences between the Department's criteria and the USEPA screening levels.

For several of the chemicals that are only weakly adsorbed to soil, the soil properties have a relatively small effect on the standard. These chemicals are marked with "SOIL" in the right column. Finally, for several metals, the soil pH influenced the adsorption coefficient used to calculate the standards. These contaminants are indicated by the "K_d" notation in the right column.

Table 1. CHEMICALS WITH NO FEDERAL SCREENING LEVELS
FOR THE IMPACT-TO-GROUNDWATER PATHWAY

Chemical	*CAS Number*
Acenaphthylene	208-96-8
Acetophenone	98-86-2
Acrolein	107-02-8
Acrylonitrile	107-13-1
Atrazine	1912-24-9
Benzaldehyde	100-52-7
Benzidine	92-87-5
Benzo(ghi)perylene	191-24-2
1,1'-Biphenyl	92-52-4
Bis(2-chloroisopropyl)ether (2,2'-oxybis(1-chloropropane))	108-60-1
2-Butanone (Methyl ethyl ketone) (MEK)	78-93-3
Caprolactam	105-60-2
Chloroethane	75-00-3
Chloromethane (Methyl chloride)	74-87-3
4-Chloro-3-methyl phenol (p-Chloro-m-cresol)	59-50-7
Dibenzofuran	132-64-9
1,2-Dibromo-3-chloropropane	96-12-8
1,2-Dibromoethane	106-93-4
1,3-Dichlorobenzene (m-Dichlorobenzene)	541-73-1
Dichlorodifluoromethane	75-71-8
Dimethylphthalate	131-11-3
4,6-Dinitro-2-methylphenol	534-52-1
1,2-Diphenylhydrazine	122-66-7
Endosulfan sulfate	1031-07-8
2-Hexanone	591-78-6
Methyl acetate	79-20-9
Methylcyclohexane	108-87-2
4-Methyl-2-pentanone (MIBK)	108-10-1
4-Methylphenol (p-cresol)	106-44-5
MTBE (tert-butyl methyl ether)	1634-04-4
2-Nitroaniline	88-74-4
4-Nitrophenol	100-02-7
N-Nitrosodimethylamine	62-75-9
PCBs (Polychlorinated biphenyls) (summed)	1336-36-3
Phenanthrene	85-01-8
Tertiary butyl alcohol (TBA)	75-65-0
Trichlorofluoromethane	75-69-4
1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1

Table 2. **CHEMICALS WITH DEP CRITERIA MORE STRINGENT THAN FEDERAL SCREENING LEVELS FOR THE IMPACT TO GROUND WATER PATHWAY.**

Chemical	*CAS Number*	*EPA Target Ground water Concentration (mg/L) (1996 SSL Guidance Doc.) (MCL, MCLG, or HBL)*	*NJDEP Target Ground water Concentration (mg/L) (Health-based criteria)*	*EPA Impact to Ground water Screening Levels (mg/kg) DAF=20*	*Proposed Generic Impact to Ground water Soil Remediation Standards (mg/kg) DAF = 12*	*Parameters Affecting Difference in Cleanup Standard[a]*
Acenaphthene	83-32-9	2	0.4	570	69.0	DAF, *GW*
Acetone (2-propanone)	67-64-1	4	0.7	16	1.0	DAF, *GW, SOIL*
Aldrin	309-00-2	0.000005	0.000002	0.5	0.1	DAF, *GW*
Anthracene	120-12-7	10	2	12000	1400	DAF, *GW*
Antimony (total)	7440-36-0	0.006	0.002	5	1.0	DAF, *GW*
Arsenic (total)	7440-38-2	0.05	0.00002	29	0.006	DAF, *GW*
Barium (total)	7440-39-3	2	2	1600	270	DAF, *Kd*
Benzene	71-43-2	0.005	0.0002	0.03	0.0007	DAF, *GW, SOIL*
Benzo(a)anthracene (1,2-Benzanthracene)	56-55-3	0.0001	0.00005	2	0.5	DAF, *GW*
Benzo(a)pyrene	50-32-8	0.0002	0.000005	8	0.1	DAF, *GW*
Benzo(b)fluoranthene (3,4-Benzofluoranthene)	205-99-2	0.0001	0.00005	5	1.0	DAF, *GW*
Benzo(k)fluoranthene	207-08-9	0.001	0.0005	49	15	DAF, *GW*
Beryllium	7440-41-7	0.004	0.000008	63	0.002	DAF, *GW, Kd*
Bis(2-chloroethyl)ether	111-44-4	0.00008	0.00003	0.0004	0.00007	DAF, *GW, SOIL*
Bis(2-ethylhexyl)phthalate	117-81-7	0.006	0.003	3600	1000	DAF, *GW*
Bromodichloromethane (Dichlorobromomethane)	75-27-4	0.1	0.0003	0.6	0.000976	DAF, *GW, SOIL*
Bromoform	75-25-2	0.1	0.004	0.8	0.0158	DAF, *GW, SOIL*
Bromomethane (Methyl bromide)	74-83-9	0.05	0.01	0.2	0.0246	DAF, *GW*
Butylbenzyl phthalate	85-68-7	7	0.1	930	138	DAF, *GW*
Cadmium	7440-43-9	0.005	0.004	8	0.727	DAF, *GW, Kd*
Carbon disulfide	75-15-0	4	0.8	32	3.78	DAF, *GW, SOIL*
Carbon tetrachloride	56-23-5	0.005	0.0004	0.07	0.00313	DAF, *GW*
Chlordane (alpha and gamma forms summed)	57-74-9	0.002	0.00001	10	0.03	DAF, *GW*
4-Chloroaniline (p-Chloroaniline)	106-47-8	0.1	0.03	0.7	0.103	DAF, *GW, SOIL*
Chlorobenzene	108-90-7	0.1	0.05	1	0.366	DAF, *GW*
Chloroform	67-66-3	0.1	0.006	0.6	0.02	DAF, *GW*
2-Chlorophenol (o-Chlorophenol)	95-57-8	0.2	0.04	4	0.447	DAF, *GW*
Chrysene	218-01-9	0.01	0.005	160	47.8	DAF, *GW*
Cyanide	57-12-5	0.2	0.2	40	24.1	DAF *only*
4,4'-DDD (p,p'-TDE)	72-54-8	0.0004	0.0001	16	2.4	DAF, *GW*
4,4'-DDE (p,p'-DDX)	72-55-9	0.0003	0.0001	54	10.7	DAF, *GW*
4,4'-DDT	50-29-3	0.0003	0.0001	32	6.31	DAF, *GW*
Dibenz(a,h)anthracene	53-70-3	0.00001	0.000005	2	0.456	DAF, *GW*
Dibromochloromethane (Chlorodibromomethane)	124-48-1	0.06	0.01	0.4	0.034	DAF, *GW, SOIL*
1,2-Dichlorobenzene (o-Dichlorobenzene)	95-50-1	0.6	0.6	17	10.1	DAF *only*
1,4-Dichlorobenzene (p-Dichlorobenzene)	106-46-7	0.075	0.075	2	1.26	DAF *only*
3,3'-Dichlorobenzidine	91-94-1	0.0002	0.00008	0.007	0.00154	DAF, *GW*
1,1-Dichloroethane	75-34-3	4	0.05	23	0.146	DAF, *GW, SOIL*
1,2-Dichloroethane	107-06-2	0.005	0.0003	0.02	0.000695	DAF, *GW, SOIL*
1,1-Dichloroethene (1,1-Dichloroethylene)	75-35-4	0.007	0.001	0.06	0.00479	DAF, *GW*

Chemical	CAS Number	EPA Target Ground water Concentration (mg/L) (1996 SSL Guidance Doc.) (MCL, MCLG, or HBL)	NJDEP Target Ground water Concentration (mg/L) (Health-based criteria)	EPA Impact to Ground water Screening Levels (mg/kg) DAF=20	Proposed Generic Impact to Ground water Soil Remediation Standards (mg/kg) DAF = 12	Parameters Affecting Difference in Cleanup Standard[a]
1,2-Dichloroethene (cis) (c-1,2-Dichloroethylene)	156-59-2	0.07	0.07	0.4	0.205	DAF *only*
1,2-Dichloroethene (trans) (t-1,2-Dichloroethylene)	156-60-5	0.1	0.1	0.7	0.365	DAF, *SOIL*
2,4-Dichlorophenol	120-83-2	0.1	0.02	1	0.107	DAF, *GW*
1,2-Dichloropropane	78-87-5	0.005	0.0005	0.03	0.00153	DAF, *GW, SOIL*
1,3-Dichloropropene (cis and trans) (summed)	542-75-6	0.0005	0.0002	0.004	0.000796	DAF, *GW, SOIL*
Dieldrin	60-57-1	0.000005	0.000002	0.004	0.00103	DAF, *GW*
Diethylphthalate	84-66-2	30	5	470	43.8	DAF, *GW, SOIL*
2,4-Dimethylphenol	105-67-9	0.7	0.1	9	0.686	DAF, *GW, SOIL*
Di-n-butyl phthalate	84-74-2	4	0.9	2300	730	DAF, *GW*
2,4-Dinitrophenol	51-28-5	0.04	0.01	0.3	0.02	DAF, *GW*
2,4-Dinitrotoluene	121-14-2	0.0001	0.00005	0.0008	0.000207	DAF, *GW*
2,6-Dinitrotoluene	606-20-2	0.0001	0.00005	0.0007	0.0002	DAF, *GW*
Di-n-octyl phthalate	117-84-0	0.7	0.1	10000	330(a)	DAF, *GW*
Endosulfan I and Endosulfan II (alpha and beta) (summed)	115-29-7	0.2	0.0004	18	0.0213	DAF, *GW*
Endrin	72-20-8	0.002	0.002	1	0.594	DAF *only*
Ethylbenzene	100-41-4	0.7	0.7	13	7.71	DAF *only*
Fluoranthene	206-44-0	1	0.3	4300	771	DAF, *GW*
Fluorene	86-73-7	1	0.3	560	99.9	DAF, *GW*
alpha-HCH (alpha-BHC)	319-84-6	0.00001	0.000006	0.0005	0.0002	DAF, *GW*
Heptachlor	76-44-8	0.0004	0.000008	23	0.271	DAF, *GW*
Heptachlor epoxide	1024-57-3	0.0002	0.000004	0.7	0.00799	DAF, *GW*
Hexachlorobenzene	118-74-1	0.001	0.00002	2	0.0264	DAF, *GW*
Hexachloro-1,3-butadiene	87-68-3	0.001	0.001	2	1.29	DAF *only*
Hexachlorocyclopentadiene	77-47-4	0.05	0.05	400	240	DAF *only*
Hexachloroethane	67-72-1	0.006	0.0007	0.5	0.0314	DAF, *GW*
Indeno(1,2,3-cd)pyrene	193-39-5	0.0001	0.00005	14	4.16	DAF, *GW*
Isophorone	78-59-1	0.09	0.1	0.5	0.3	DAF, *GW*
Lindane (gamma-HCH) (gamma-BHC)	58-89-9	0.0002	0.0002	0.009	0.0055	DAF *only*
Mercury (total)	7439-97-6	0.002	0.002	2	0.00598	DAF, *Kd*
Methoxychlor	72-43-5	0.04	0.04	160	93.9	DAF, *SOIL*
Methylene chloride (Dichloromethane)	75-09-2	0.005	0.003	0.02	0.00675	DAF, *GW, SOIL*
Naphthalene	91-20-3	1	0.3	84	15	DAF, *GW*
Nickel (total)	7440-02-0	0.1	0.1	130	19.4	DAF, *Kd*
Nitrobenzene	98-95-3	0.02	0.003	0.1	0.0102	DAF, *GW, SOIL*
N-Nitrosodi-n-propylamine	621-64-7	0.00001	0.000005	0.00005	0.0000121	DAF, *GW*
N-Nitrosodiphenylamine	86-30-6	0.02	0.007	1	0.23	DAF, *GW*
Pentachlorophenol	87-86-5	0.001	0.0003	0.03	0.00481	DAF, *GW*
Phenol	108-95-2	20	4	100	10.1	DAF, *GW, SOIL*
Pyrene	129-00-0	1	0.2	4200	504	DAF, *GW*
Selenium (total)	7782-49-2	0.05	0.05	5	3.09	DAF *only*
Silver (total)	7440-22-4	0.2	0.03	34	0.0912	DAF, *GW, Kd*
Styrene	100-42-5	0.1	0.1	4	2.06	DAF *only*
Tetrachloroethene (PCE) (Tetrachloroethylene)	127-18-4	0.005	0.0004	0.06	0.00266	DAF, *GW*

Chemical	*CAS Number*	*EPA Target Ground water Concentration (mg/L) (1996 SSL Guidance Doc.) (MCL, MCLG, or HBL)*	*NJDEP Target Ground water Concentration (mg/L) (Health-based criteria)*	*EPA Impact to Ground water Screening Levels (mg/kg)* DAF=*20*	*Proposed Generic Impact to Ground water Soil Remediation Standards (mg/kg)* DAF = *12*	*Parameters Affecting Difference in Cleanup Standard*[a]
Thallium (total)	7440-28-0	0.0005	0.0005	0.7	0.265	DAF, *Kd*
Toluene	108-88-3	1	1	12	6.6	DAF *only*
Toxaphene	8001-35-2	0.003	0.00003	31	0.2	DAF, *GW*
1,2,4-Trichlorobenzene	*120-82-1*	*0.07*	*0.009*	*5*	*0.402*	DAF, *GW*
1,1,1-Trichloroethane	71-55-6	0.2	0.03	2	0.2	DAF, *GW*
1,1,2-Trichloroethane	79-00-5	0.003	0.003	0.02	0.00929	DAF, *SOIL*
Trichloroethene (TCE) (Trichloroethylene)	79-01-6	0.005	0.001	0.06	0.00643	DAF, *GW*
2,4,5-Trichlorophenol	95-95-4	4	0.7	270	28.2	DAF, *GW*
2,4,6-Trichlorophenol	88-06-2	0.008	0.003	0.2	0.033	DAF, *GW*
Vinyl chloride	75-01-4	0.002	0.00008	0.01	0.000311	DAF, *GW*
Xylenes (total)	1330-20-7	10	1	200	11.5	DAF, *GW, SOIL*
Zinc (total)	7440-66-6	10	5	12000	969	DAF, *GW, Kd*

a DAF = Dilution-attenuation factor; GW = Ground water criteria; Kd = Soil adsorption coefficient; SOIL = soil properties
MCL= Maximum Contaminant Level; MCLG=Maximium Contaminant Level Goal; HCL= Health Based Limit.

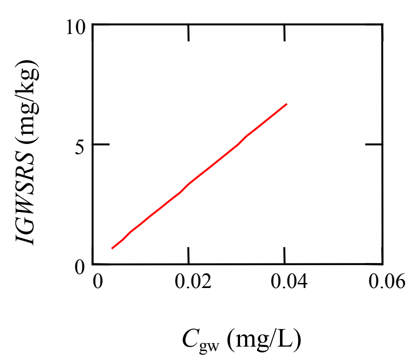
APPENDIX B
Sensitivity of the USEPA Partitioning Equation to Modification of Component Parameters

The Department conducted a sensitivity analysis of the USEPA partitioning equation to determine the effects of modifying different equation parameters on the development of soil remediation standards. For this analysis, one variable was modified at a time, with the other chemical and environmental parameter values were set at generic New Jersey values. Soil properties were varied within their normal ranges (USEPA, 1996b). The analysis was conducted in two phases. First, the sensitivity of Equations 1 and 2 was evaluated with respect to the organic carbon content, K_{oc}, K_d, Henry's law constant, ground water criteria, the dilution-attenuation factor (DAF), soil moisture, soil air content, and soil bulk density. Second, the sensitivity of the DAF calculations (Equations 3 and 4) to the various parameters incorporated was evaluated. The examples below are for specific contaminants, but the observed sensitivities are the same for all contaminants.

1. Sensitivity of the remediation standard (*IGWSRS*) to changes to the ground water criteria (C_{gw}).
   Results shown for cadmium.

C_{gw} (mg/L)	*IGWSRS* (mg/kg)
0.004	0.663
0.006	0.995
0.008	1.326
0.01	1.658
0.012	1.989
0.014	2.321
0.016	2.652
0.018	2.984
0.02	3.315
0.022	3.647
0.024	3.978
0.026	4.31
0.028	4.641
0.03	4.973
0.032	5.305
0.034	5.636
0.036	5.968
0.038	6.299
0.04	6.631

Sensitivity to groundwater criteria is linear

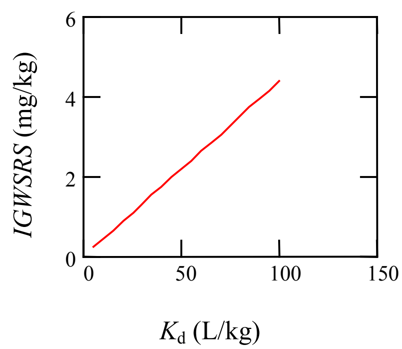


2. Sensitivity of remediation standard (*IGWSRS*) to changes to the soil-water partition coefficient (K_d) value.

Results shown for cadmium.

K_d (L/kg)	*IGWSRS* (mg/kg)
5	0.225
10	0.444
15	0.663
20	0.882
25	1.101
30	1.139
35	1.538
40	1.757
45	1.976
50	2.195
55	2.413
60	2.632
65	2.851
70	3.07
75	3.288
80	3.507
85	3.726
90	3.945
95	4.164
100	4.382

Sensitivity to K_d is linear.

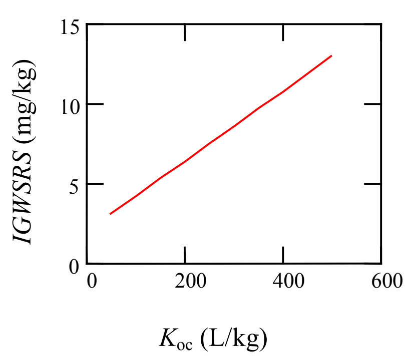


3. Sensitivity of remediation standard (*IGWSRS*) to changes to the (K_{oc}) soil organic carbon-water partition coefficient value.

Results shown for xylenes.

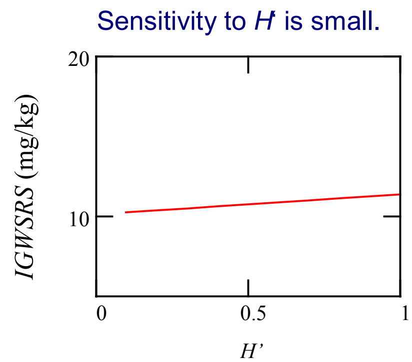
Sensitivity to K_{oc} is linear.

K_{oc} (L/kg)	*IGWSRS* (mg/kg)
50	3.134
100	4.228
150	5.321
200	6.415
250	7.509
300	8.603
350	9.697
400	10.791
450	11.885
500	12.979



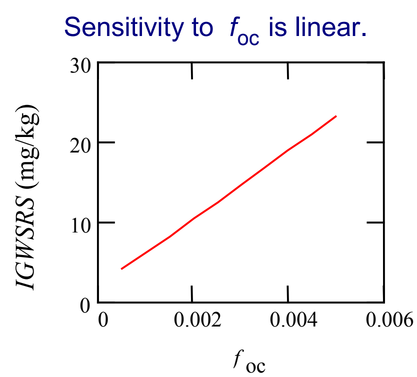
4. Sensitivity of remediation standard (*IGWSRS*) to the Henry's law constant (*H'*). Results shown for xylenes.

H'	*IGWSRS* (mg/kg)
0.1	10.254
0.2	10.385
0.3	10.516
0.4	10.648
0.5	10.779
0.6	10.91
0.7	11.041
0.8	11.173
0.9	11.304
1	11.435



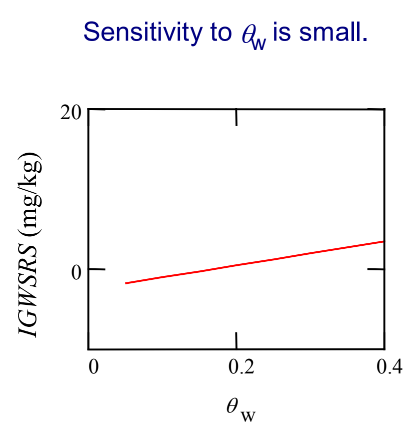
5. Sensitivity of remediation standard (*IGWSRS*) to fraction organic carbon (f_{oc}). Results shown for xylenes.

f_{oc}	*IGWSRS* (mg/kg)
0.0005	4.151
0.001	6.262
0.0015	8.374
0.002	10.485
0.0025	12.596
0.003	14.707
0.0035	16.819
0.004	18.93
0.0045	21.041
0.005	23.152



6. Sensitivity of remediation standard (*IGWSRS*) to soil moisture (θ_w)
Results shown for xylenes.

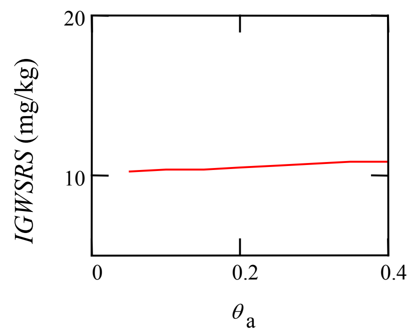
θ_w	*IGWSRS* (mg/kg)
0.0005	4.151
0.001	6.262
0.0015	8.374
0.002	10.485
0.0025	12.596
0.003	14.707
0.0035	16.819
0.004	18.93
0.0045	21.041
0.005	23.152



7. Sensitivity of remediation standard (*IGWSRS*) to soil air content (θ_a). Results shown for xylenes.

θ_a	*IGWSRS* (mg/kg)
0.05	10.223
0.1	10.324
0.15	10.424
0.2	10.525
0.25	10.626
0.3	10.726
0.35	10.827
0.4	10.928

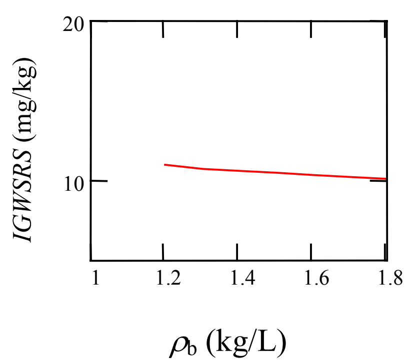
Sensitivity to θ_a is small



8. Sensitivity of remediation standard (*IGWSRS*) to soil bulk density (ρ_b) Results shown for xylenes

Sensitivity to ρ_b is small.

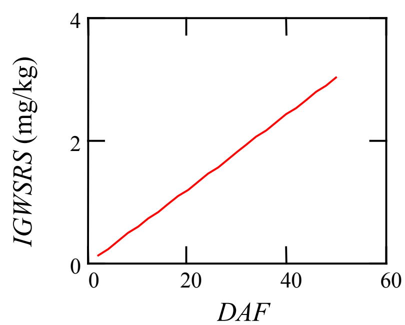
ρ_b (kg/L)	*IGWSRS* (mg/kg)
0.05	10.223
0.1	10.324
0.15	10.424
0.2	10.525
0.25	10.626
0.3	10.726
0.35	10.827
0.4	10.928



9. Sensitivity of remediation standard (*IGWSRS*) to Dilution Attenuation Factor (DAF). Results shown for cadmium.

DAF	*IGWSRS* (mg/kg)
2	0.121
4	0.242
6	0.364
8	0.485
10	0.606
12	0.727
14	0.849
16	0.97
18	1.091
20	1.212
22	1.333
24	1.455
26	1.576
28	1.697
30	1.818
32	1.94
34	2.061
36	2.182
38	2.303
40	2.425
42	2.546
44	2.667
46	2.788
48	2.909
50	3.031

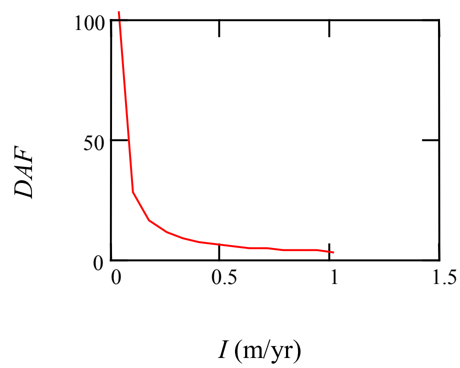
Sensitivity is linear with respect to *DAF*



10. Sensitivity of Dilution Attenuation Factor (DAF) (and remediation standard (*IGWSRS*)) to infiltration rate (*I*). Results shown for cadmium.

I (m/yr)	*DAF*
0.025	110.567
0.102	28.392
0.178	16.652
0.254	11.957
0.33	9.428
0.406	7.848
0.483	6.767
0.559	5.98
0.635	5.383
0.711	4.913
0.787	4.534
0.864	4.223
0.94	3.961
1.016	3.739

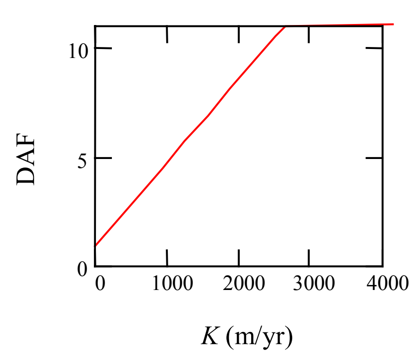
DAF (and cleanup standard) sensitivity is inversely proportional to infiltration rate, *I*. This is for a thin aquifer (10 feet). Mixing zone depth is equal to entire aquifer thickness at all infiltration rates.



11. Sensitivity of dilution attenuation factor (DAF) (and remediation standard (*IGWSRS*)) to hydraulic conductivity (*K*). Results are shown for cadmium.

DAF (and cleanup standard) sensitivity is slightly less than linear with respect to conductivity, *K*. This is under generic conditions, which includes a thin aquifer (10 feet). Mixing zone depth is equal to entire aquifer thickness at all conductivities.

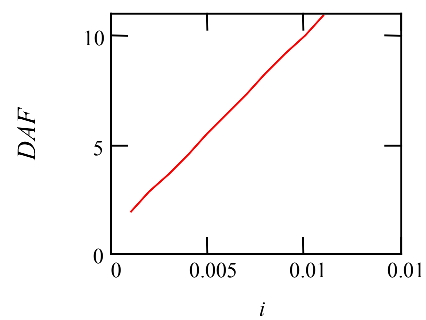
K (m/yr)	*DAF*
0.3	1.001
315	2.24
630	3.478
946	4.717
1261	5.955
1576	7.194
1891	8.432
2207	9.671
2522	10.909
2837	12.148
3152	13.386



12. Sensitivity of dilution attenuation factor (DAF) and remediation standard (*IGWSRS*) to gradient (i). Results are shown for cadmium.

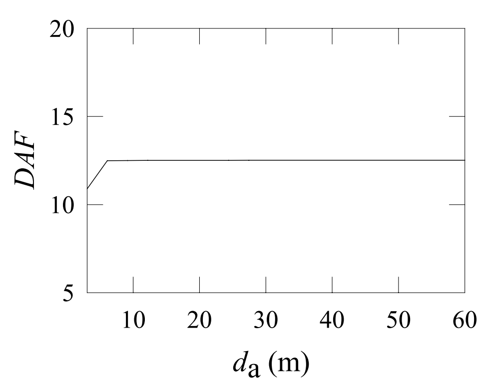
i	*DAF*
0.001	1.904
0.002	2.807
0.003	3.711
0.004	4.614
0.005	5.518
0.006	6.421
0.007	7.325
0.008	8.229
0.009	9.132
0.01	10.036
0.011	10.939

DAF (and cleanup standard) sensitivity is slightly less than linear with respect to gradient, *i*. This is under our generic conditions, which includes a thin aquifer (10 feet). Mixing zone depth is equal to entire aquifer thickness for all gradients.



13. Sensitivity of dilution attenuation factor (DAF) (and remediation standard (*IGWSRS*)) to aquifer thickness (d_a). Results shown for cadmium.

Discussion: As the aquifer thickness was raised from 3.05 m to 60 m, the mixing zone depth increased only slightly, from 3.05 to 3.53 m, and the DAF increased only slightly, from 10.9 to 12.5. This indicates that the aquifer thickness has little effect on the DAF (and cleanup standards) when other parameters are held at generic values.



14. Effect of size of area of concern on the remediation standard.
 Results shown for benzene, xylene and cadmium.

Remediation standard (mg/kg) for
varying values of site length, *L*

Aquifer thickness = 3.05 (generic conditions)

	Length of Site Parallel to GW flow (m)		
	15.2	*30.5*	*152*
Benzene	0.0007	0.0006	0.0002
Xylene	12	10	3
Cadmium	0.8	0.7	0.2

Aquifer thickness = 15.2 m

	Length of Site Parallel to GW flow (m)		
	15.2	*30.5*	*152*
Benzene	0.0007	0.0007	0.0006
Xylene	12	12	10
Cadmium	0.8	0.8	0.7

The first chart above (generic conditions) shows that a lower generic cleanup number results when the site length becomes large. However, if the aquifer thickness is increased from 3.05 m to 15.2 m (second chart above), this effect does not occur. Therefore, the generic cleanup standard is reasonably protective, but not completely protective of large sites over thin aquifers (as shown by the 3.05 m foot thick aquifer chart). However, the generic standard does appear to be adequately protective for all site sizes as the aquifer thickness is increased.

APPENDIX C
Chemical Properties for Calculation of Generic
Impact to Ground Water Soil Remediation Standards

	Chemical	CAS Number	Henry's law constant (dimensionless)		Water solubility mg/L		DEP K_{oc} (mL/g)		DEP Kd (mL/g)		DEP Soil Saturation Limit (mg/kg)
1	Acenaphthene	83-32-9	6.36E-03	a	4.24E+00	a	7.08E+03	a			
2	Acenaphthylene	208-96-8	0.00451	f	16	f	2759	i			
3	Acetone (2-propanone)	67-64-1	1.59E-03	a	1.00E+06	a	5.75E-01	a			1.55E+05
4	Acetophenone	98-86-2	0.000451	f	6.10E+03	f	37	i			1.39E+03
5	Acrolein	107-02-8	0.00492	f	2.10E+05	f	1	i			3.27E+04
6	Acrylonitrile	107-13-1	0.0041	f	7.40E+04	f	2	i			1.17E+04
7	Aldrin	309-00-2	6.97E-03	a	1.80E-01	a	2.45E+06	a			
8	Aluminum (total)	7429-90-5	0	c					1.50E+03	f	
9	Anthracene	120-12-7	2.67E-03	a	4.34E-02	a	2.95E+04	a			
10	Antimony (total)	7440-36-0	0	c					4.50E+01	a	
11	Arsenic (total)	7440-38-2	0	c					2.50E+01	a,e	
12	Atrazine	1912-24-9	1.21E-07	g	70	f	360	i			
13	Barium (total)	7440-39-3	0	c					1.10E+01	a,e	
14	Benzaldehyde	100-52-7	0.00109	g	3000	g	29	i,k			6.34E+02
15	Benzene	71-43-2	2.28E-01	a	1.75E+03	a	5.89E+01	a			5.22E+02
16	Benzidine	92-87-5	1.60E-09	f	500	f	47	i			
17	Benzo(a)anthracene	56-55-3	1.37E-04	a	9.40E-03	a	3.98E+05	a			
18	Benzo(a)pyrene	50-32-8	4.63E-05	a	1.62E-03	a	1.02E+06	a			
19	Benzo(b)fluoranthene	205-99-2	4.55E-03	a	1.50E-03	a	1.23E+06	a			
20	Benzo(ghi)perylene	191-24-2	5.74E-06	f	2.60E-04	f	3858158	i			
21	Benzo(k)fluoranthene	207-08-9	3.40E-05	a	8.00E-04	a	1.23E+06	a			
22	Beryllium	7440-41-7	0	c					2.30E+01	a,e	
23	1,1'-Biphenyl	92-52-4	0.0123	f	6	f	8556	i			
24	Bis(2-chloroethyl)ether	111-44-4	7.38E-04	a	1.72E+04	a	1.55E+01	a			3.17E+03
25	Bis(2-chloroisopropyl)ether	108-60-1	0.00303	g	1.30E+03	f	360	i			1.14E+03
26	Bis(2-ethylhexyl)phthalate	117-81-7	4.18E-06	a	3.40E-01	a	1.51E+07	a			1.03E+04
27	Bromodichloromethane	75-27-4	6.56E-02	a	6.74E+03	a	5.50E+01	a			1.83E+03
28	Bromoform	75-25-2	2.19E-02	a	3.10E+03	a	8.71E+01	a			1.02E+03
29	Bromomethane	74-83-9	2.56E-01	a	1.52E+04	a	1.05E+01	a			3.12E+03
30	2-Butanone (MEK)	78-93-3	0.002296	f	2.20E+05	f	1	i			3.42E+04
31	Butylbenzyl phthalate	85-68-7	5.17E-05	a	2.69E+00	a	5.75E+04	a			3.10E+02
32	Cadmium	7440-43-9	0	c					1.50E+01	a,e	
33	Caprolactam	105-60-2	1.50E-07	h	3.01E+05	h	6	i,l			
34	Carbazole	86-74-8	6.27E-07	a	7.48E+00	a	3.39E+03	a			
35	Carbon disulfide	75-15-0	1.24E+00	a	1.19E+03	a	4.57E+01	a			4.68E+02
36	Carbon tetrachloride	56-23-5	1.25E+00	a	7.93E+02	a	1.74E+02	a			5.17E+02
37	Chlordane (alpha and gamma)	57-74-9	1.99E-03	a	5.60E-02	a	1.20E+05	a			
38	4-Chloroaniline (p-Chloroaniline)	106-47-8	1.36E-05	a	5.30E+03	a	6.61E+01	a			
39	Chlorobenzene	108-90-7	1.52E-01	a	4.72E+02	a	2.19E+02	a			2.88E+02
40	Chloroethane	75-00-3	0.3608	f	5.70E+03	f	15	j			
41	Chloroform	67-66-3	1.50E-01	a	7.92E+03	a	3.98E+01	a			1.99E+03
42	Chloromethane	74-87-3	0.3608	f	5.30E+03	f	6	j			
43	4-Chloro-3-methyl phenol	59-50-7	0.0000164	f	3.80E+03	f	1116	i			
44	2-Chlorophenol (o-Chlorophenol)	95-57-8	1.60E-02	a	2.20E+04	a	3.88E+02	a,d			2.05E+04
45	Chromium (III)	16065-83-1	0	c					1.20E+03	a,e	
46	Chromium (VI)	18540-29-9	0	c					1.90E+01	a,d	
47	Chromium (total)	7440-47-3	0	c					1.90E+01	a,d	
48	Chrysene	218-01-9	3.88E-03	a	1.60E-03	a	3.98E+05	a			
49	Cobalt (total)	7440-48-4	0	c					4.50E+01	f	
50	Copper (total)	7440-50-8	0	c					4.30E+02	f	
51	Cyanide	57-12-5	0	c					9.90E+00	a	
52	4,4'-DDD (p,p'-TDE)	72-54-8	1.64E-04	a	9.00E-02	a	1.00E+06	a			

	Chemical	CAS Number	Henry's law constant (dimensionless)		Water solubility mg/L		DEP K_{oc} (mL/g)		DEP Kd (mL/g)		DEP Soil Saturation Limit (mg/kg)
53	4,4'-DDE (p,p'-DDX)	72-55-9	8.61E-04	a	1.20E-01	a	4.47E+06	a			
54	4,4'-DDT	50-29-3	3.32E-04	a	2.50E-02	a	2.63E+06	a			
55	Dibenz(a,h)anthracene	53-70-3	6.03E-07	a	2.49E-03	a	3.80E+06	a			
56	Dibenzofuran	132-64-9	0.000533	f	10	f	13455	i			2.71E+02
57	Dibromochloromethane	124-48-1	3.21E-02	a	2.60E+03	a	6.31E+01	a			7.37E+02
58	1,2-Dibromo-3-chloropropane	96-12-8	0.00615	f	1.20E+03	f	79	j			3.74E+02
59	1,2-Dibromoethane	106-93-4	0.03034	f	4.20E+03	f	46	j			1.05E+03
60	1,2-Dichlorobenzene	95-50-1	7.79E-02	a	1.56E+02	a	6.17E+02	a			2.18E+02
61	1,3-Dichlorobenzene	541-73-1	0.1271	f	130	f	708	j			2.06E+02
62	1,4-Dichlorobenzene	106-46-7	9.96E-02	a	7.38E+01	a	6.17E+02	a			
63	3,3'-Dichlorobenzidine	91-94-1	1.64E-07	a	3.11E+00	a	7.24E+02	a			
64	Dichlorodifluoromethane	75-71-8	13.94	f	280	f	66	j			
65	1,1-Dichloroethane	75-34-3	2.30E-01	a	5.06E+03	a	3.16E+01	a			1.24E+03
66	1,2-Dichloroethane	107-06-2	4.01E-02	a	8.52E+03	a	1.74E+01	a			1.64E+03
67	1,1-Dichloroethene	75-35-4	1.07E+00	a	2.25E+03	a	5.89E+01	a			8.99E+02
68	1,2-Dichloroethene (cis)	156-59-2	1.67E-01	a	3.50E+03	a	3.55E+01	a			8.55E+02
69	1,2-Dichloroethene (trans)	156-60-5	3.85E-01	a	6.30E+03	a	5.25E+01	a			1.92E+03
70	2,4-Dichlorophenol	120-83-2	1.30E-04	a	4.50E+03	a	1.47E+02	a,d			
71	1,2-Dichloropropane	78-87-5	1.15E-01	a	2.80E+03	a	4.37E+01	a			7.13E+02
72	1,3-Dichloropropene (cis & trans)	542-75-6	7.26E-01	a	2.80E+03	a	4.57E+01	a			9.29E+02
73	Dieldrin	60-57-1	6.19E-04	a	1.95E-01	a	2.14E+04	a			
74	Diethylphthalate	84-66-2	1.85E-05	a	1.08E+03	a	2.88E+02	a			7.88E+02
75	2,4-Dimethylphenol	105-67-9	8.20E-05	a	7.87E+03	a	2.09E+02	a			
76	Dimethylphthalate	131-11-3	4.51E-06	f	4000	f	37	i			9.09E+02
77	Di-n-butyl phthalate	84-74-2	3.85E-08	a	1.12E+01	a	3.39E+04	a			7.61E+02
78	4,6-Dinitro-2-methylphenol	534-52-1	1.76E-05	f	200	f	116	i			
79	2,4-Dinitrophenol	51-28-5	1.82E-05	a	2.79E+03	a	1.00E-02	a,d			
80	2,4-Dinitrotoluene	121-14-2	3.80E-06	a	2.70E+02	a	9.55E+01	a			
81	2,6-Dinitrotoluene	606-20-2	3.06E-05	a	1.82E+02	a	6.92E+01	a			
82	Di-n-octyl phthalate	117-84-0	2.74E-03	a	2.00E-02	a	8.32E+07	a			3.33E+03
83	Dioxin (2,3,7,8-TCDD)	1746-01-6	0.003239	f	7.90E-06	f	2453466	i			
84	1,2-Diphenylhydrazine	122-66-7	0.0000615	f	68	f	710	i			
85	Endosulfan I and Endosulfan II	115-29-7	4.59E-04	a	5.10E-01	a	2.14E+03	a			
86	Endosulfan sulfate	1031-07-8	0.0861	f	6.4	f	1020	j			
87	Endrin	72-20-8	3.08E-04	a	2.50E-01	a	1.23E+04	a			
88	Ethylbenzene	100-41-4	3.23E-01	a	1.69E+02	a	3.63E+02	a			1.55E+02
89	Fluoranthene	206-44-0	6.60E-04	a	2.06E-01	a	1.07E+05	a			
90	Fluorene	86-73-7	2.61E-03	a	1.98E+00	a	1.38E+04	a			
91	alpha-HCH (alpha-BHC)	319-84-6	4.35E-04	a	2.00E+00	a	1.23E+03	a			
92	beta-HCH (beta-BHC)	319-85-7	3.05E-05	a	2.40E-01	a	1.26E+03	a			
93	Heptachlor	76-44-8	6.07E+01	a	1.80E-01	a	1.41E+06	a			
94	Heptachlor epoxide	1024-57-3	3.90E-04	a	2.00E-01	a	8.32E+04	a			
95	Hexachlorobenzene	118-74-1	5.41E-02	a	6.20E+00	a	5.50E+04	a			
96	Hexachloro-1,3-butadiene	87-68-3	3.34E-01	a	3.23E+00	a	5.37E+04	a			3.48E+02
97	Hexachlorocyclopentadiene	77-47-4	1.11E+00	a	1.80E+00	a	2.00E+05	a			7.21E+02
98	Hexachloroethane	67-72-1	1.59E-01	a	5.00E+01	a	1.78E+03	a			
99	2-Hexanone	591-78-6	0.0038	g	1.80E+04	f	24	i			3.63E+03
100	Indeno(1,2,3-cd)pyrene	193-39-5	6.56E-05	a	2.20E-05	a	3.47E+06	a			
101	Isophorone	78-59-1	2.72E-04	a	1.20E+04	a	4.68E+01	a			2.96E+03
102	Lead (total)	7439-92-1	0	c					9.00E+02	f	
103	Lindane (gamma-HCH or BHC)	58-89-9	5.74E-04	a	6.80E+00	a	1.07E+03	a			
104	Manganese (total)	7439-96-5	0	c					6.50E+01	f	
105	Mercury (total)	7439-97-6	4.67E-01	a					4.00E-02	a,e	
106	Methoxychlor	72-43-5	6.48E-04	a	4.50E-02	a	9.77E+04	a			
107	Methyl acetate	79-20-9	0.021	g	2.40E+05	g	2	i,k			3.84E+04
108	Methylcyclohexane	108-87-2	17.6	g	14	g	865	j,k			5.59E+01
109	Methylene chloride	75-09-2	8.98E-02	a	1.30E+04	a	1.17E+01	a			2.44E+03
110	4-Methyl-2-pentanone (MIBK)	108-10-1	0.00574	f	1.90E+04	f	15	i			3.50E+03
111	2-Methylphenol (o-cresol)	95-48-7	4.92E-05	a	2.60E+04	a	9.12E+01	a			
112	4-Methylphenol (p-cresol)	106-44-5	3.24E-05	f	2.20E+04	f	74	i			

	Chemical	CAS Number	Henry's law constant (dimensionless)		Water solubility mg/L		DEP K_{oc} (mL/g)		DEP Kd (mL/g)		DEP Soil Saturation Limit (mg/kg)
113	MTBE (tert-butyl methyl ether)	1634-04-4	0.024	g	48000	g	8	i,k			8.27E+03
114	Naphthalene	91-20-3	1.98E-02	a	3.10E+01	a	2.00E+03	a			
115	Nickel (total)	7440-02-0	0	c					1.60E+01	a,e	
116	2-Nitroaniline	88-74-4	7.42E-07	g	290	f	74	i			
117	Nitrobenzene	98-95-3	9.84E-04	a	2.09E+03	a	6.46E+01	a			5.91E+02
118	4-Nitrophenol	100-02-7	1.72E-08	f	1.20E+04	f	74	i			
119	N-Nitrosodimethylamine	62-75-9	4.92E-05	f	1.00E+06	f	0.3	i			1.54E+05
120	N-Nitrosodi-n-propylamine	621-64-7	9.23E-05	a	9.89E+03	a	2.40E+01	a			
121	N-Nitrosodiphenylamine	86-30-6	2.05E-04	a	3.51E+01	a	1.29E+03	a			
122	PCBs (Polychlorinated biphenyls) (summed)	1336-36-3	0.1066	f	7.00E-01	a	3.09E+05	a			4.33E+02
123	Pentachlorophenol	87-86-5	1.00E-06	a	1.95E+03	a	5.92E+02	a,d			
124	Phenanthrene	85-01-8	0.000943	f	1.1	f	26533	i			
125	Phenol	108-95-2	1.63E-05	a	8.28E+04	a	2.88E+01	a			
126	Pyrene	129-00-0	4.51E-04	a	1.35E-01	a	1.05E+05	a			
127	Selenium (total)	7782-49-2	0	c					5.00E+00	a,d	
128	Silver (total)	7440-22-4	0	c					1.00E-01	a,e	
129	Styrene	100-42-5	1.13E-01	a	3.10E+02	a	7.76E+02	a			5.33E+02
130	Tertiary butyl alcohol (TBA)	75-65-0	4.82E-04	g	missing		2	i,k			
131	1,1,2,2-Tetrachloroethane	79-34-5	1.41E-02	a	2.97E+03	a	9.33E+01	a			1.01E+03
132	Tetrachloroethene (PCE)	127-18-4	7.54E-01	a	2.00E+02	a	1.55E+02	a			1.11E+02
133	Thallium (total)	7440-28-0	0	c					4.40E+01	a,e	
134	Toluene	108-88-3	2.72E-01	a	5.26E+02	a	1.82E+02	a			2.89E+02
135	Toxaphene	8001-35-2	2.46E-04	a	7.40E-01	a	2.57E+05	a			
136	1,2,4-Trichlorobenzene	120-82-1	5.82E-02	a	3.00E+02	a	1.78E+03	a			1.12E+03
137	1,1,1-Trichloroethane	71-55-6	7.05E-01	a	1.33E+03	a	1.10E+02	a			6.09E+02
138	1,1,2-Trichloroethane	79-00-5	3.74E-02	a	4.42E+03	a	5.01E+01	a			1.14E+03
139	Trichloroethene (TCE)	79-01-6	4.22E-01	a	1.10E+03	a	1.66E+02	a			5.90E+02
140	Trichlorofluoromethane	75-69-4	3.977	f	1.10E+03	f	114	j			9.44E+02
141	2,4,5-Trichlorophenol	95-95-4	1.78E-04	a	1.20E+03	a	1.60E+03	a,d			
142	2,4,6-Trichlorophenol	88-06-2	3.19E-04	a	8.00E+02	a	3.81E+02	a,d			
143	1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	19.68	f	170	f	410	j			5.67E+02
144	Vanadium (total)	7440-62-2	0	c					1.00E+03	a	
145	Vinyl chloride	75-01-4	1.11	a	2.76E+03	a	1.86E+01	a			
146	Xylenes (total)	1330-20-7	2.76E-01	a,b	1.75E+02	a,b	3.86E+02	a,b			1.68E+02
147	Zinc (total)	7440-66-6	0	c					1.60E+01	a,e	

a USEPA (1996b)
b Values for the 3 xylene isomers were averaged
c Compound is not volatile
d pH 6.8
e pH 4.9
f USEPA (1996c)
g Hazardous Substances Data Bank
h Calculated using WATER8 (USEPA 1994b)
i Calculated from Kow via USEPA SSL Guidance Document Equation No. 70, Kow from USEPA (1996c) unless otherwise noted
j Calculated from Kow via USEPA SSL Guidance Document Equation No. 71, Kow from USEPA (1996c) unless otherwise noted
k HSDB (1999)
l Kow calculated using WATER8 (USEPA 1994b)

APPENDIX D
Determination of Generic Soil Moisture for Remediation Standard Calculations

Generic cleanup standards are only slightly sensitive to the value of soil moisture (Apendix B). An average annual soil moisture for New Jersey sandy loam soil was determined using the simple relationship described in the USEPA Soil Screening Level User's Guide:

$$\theta_w = n(I / K_s)^{1/(2b-3)}$$

where *n* is the total soil porosity, *I* is the soil moisture infiltration rate (m/yr), K_s is the saturated hydraulic conductivity of the soil (m/yr), and the factor 1/2b+3 is determined by the soil type and is provided in a lookup table in the User's Guide. Rather than calculating soil porosity as described in the User's Guide, which would yield a value of 0.43 (assuming a bulk density of 1.5 kg/L), a value of 0.41 for sandy loam was used, which was obtained from Carsel and Parrish (1988). This reference is USEPA's data source for soil properties for the USEPA SSL document. Additionally, a K_s value of 387 m/yr for sandy loam soil (from Carsel and Parrish, 1988) was used instead of the lookup value of 230 m/yr provided in the user's guide because it is a more recent evaluation. The infiltration rate, *I*, was determined as described in Appendix E to be 0.28 m/yr.

The average soil moisture determined via this method was 0.23 (v/v). If the alternative values for porosity and K_s had been used, the soil moisture would have been calculated to be 0.25 (v/v). As shown in the sensitivity analysis (Appendix B), this alternative moisture value would have had a negligible effect on the calculated cleanup standard (only at the third significant digit).

APPENDIX E
Determination of the Generic Infiltration Rate for Generic Soil Remediation Standards

Infiltration rates for New Jersey soils were determined using a New Jersey-specific tool available from the New Jersey Geological Survey. The New Jersey Geological Survey has published a method for determining infiltration rates for New Jersey as a function of location, soil type and land use (Hoffman, 1999; Charles et al., 1996). Using several of the most commonly occurring soils in New Jersey (Tedrow, 1986), infiltration rates were calculated for each soil in each county where the soil had a significant presence (Table 1). For each calculation, data from a climate station from a municipality located in the area where the soil would occur was used. Three land uses were selected for each calculation: landscaped, bare soil, and agricultural soil. All three of these soil types assume 100% of the surface area is permeable. All sandy loam soils with significant acreage in the state (as mapped by Tedrow, 1986) were used, since this soil texture has been targeted as the default soil texture for New Jersey generic standards. In addition, other soil textures with a large presence in the state (as mapped by Tedrow, 1986) were also studied, in order to determine the overall variation of infiltration rates in the state, and to verify that sandy loam soil was appropriate as a default soil texture. One limitation of this method that should be mentioned is that the infiltration calculated (below the root zone) is assumed to be equal to ground water recharge (Charles et al., 1996).

Table 1. Recharge rates for various soils, locations, and land uses in New Jersey

Soil Name	*Primary Counties of Occurrence*	*Representative Municipality*	*Recharge (in/yr) Landscaped Open Space*	*Unvegetated*	*General Agriculture*
Sassafras sandy loam	Mercer	Washington Twp.	13.2	8.8	11.6
Sassafras sandy loam	Middlesex	South River Boro	14.2	9.3	12.5
Sassafras sandy loam	Burlington	Delran Twp.	12.8	8.5	11.3
Sassafras sandy loam	Salem	Alloway Twp.	11.6	7.9	10.2
Sassafras sandy loam	Cumberland	Bridgeton City	11	7.6	9.7
Freehold sandy loam	Monmouth	Millstone Twp.	13.1	8.6	11.5
Freehold sandy loam	Burlington	Chesterfield Twp.	13.1	8.6	11.5
Freehold sandy loam	Camden	Runnemede Boro	11.7	7.8	10.2
Freehold sandy loam	Gloucester	Swedesboro Boro	11.5	7.7	10.1
Collington sandy loam	Monmouth	Holmdel Twp.	13.4	8.5	11.7
Colts Neck sandy loam	Monmouth	Colts Neck Twp.	13.2	8.7	11.9
Westphalia sandy loam	Camden	Lindenwold Boro	11.6	7.3	10.1
Westphalia sandy loam	Gloucester	Harrison Twp.	11.4	7.3	9.9
Aura sandy loam	Gloucester	Elk Twp.	11.9	8.1	10.5
Aura sandy loam	Salem	Pittsgrove Twp.	11.7	8	10.4
Aura sandy loam	Cumberland	Upper Deerfield Twp.	11.5	7.9	10.2
Dunnellen sandy loam	Bergen	Oradell Boro	16.4	10.3	14.4
Dunnellen sandy loam	Union	Plainfield City	15.6	9.9	13.8
Dunnellen sandy loam	Middlesex	Piscataway Twp.	15.1	9.7	13.3
Galestown sand	Mercer	Trenton City	15.1	13	14.3
Galestown sand	Burlington	Burlington City	14.9	12.8	14.1
Lakewood sand	Monmouth	Neptune Twp.	17.5	14.7	16.6
Lakewood sand	Ocean	Manchester Twp.	17.2	14.4	16.3
Lakewood sand	Burlington	Pemberton Twp.	15.5	13.3	14.7
Downer loamy sand	Monmouth	Neptune Twp.	16.2	10.8	14.6
Downer loamy sand	Ocean	Manchester Twp.	15.9	10.6	14.2
Downer loamy sand	Burlington	Pemberton Twp.	14.4	9.7	12.9
Downer loamy sand	Atlantic	Galloway Twp.	11.5	7.9	10.2
Downer loamy sand	Cumberland	Vineland City	12.3	8.5	11
Hammonton loamy sand	Atlantic	Estelle Manor City	12.1	8.5	10.7
Hammonton loamy sand	Cumberland	Hopewell Twp.	12.1	8.5	10.7
Hammonton loamy sand	Cape May	Lower Twp.	10.2	7.4	8.9
Boonton loam	Passaic	Hawthorne Boro	13.9	6.4	11.6
Boonton loam	Hudson	Harrison Town	10.1	4.7	8.5
Boonton loam	Essex	Newark City	10.1	4.7	8.5
Boonton loam	Union	Roselle Park	10.1	4.7	8.5
Boonton loam	Middlesex	Perth Amboy City	13.1	6	10.9
Boonton loam	Bergen	Ramsey Boro	13.9	6.4	11.6
Rockaway loam	Passaic	Ringwood Boro	17.2	8.6	14.6
Rockaway loam	Morris	Rockaway Twp.	16.5	8.3	14
Rockaway loam	Sussex	Franklin Boro	15.2	7.7	13
Annandale loam	Morris	Chester Twp.	16.9	8.4	13.9
Annandale loam	Warren	Pohatcong Twp.	12.4	6.7	10.2
Annandale loam	Hunterdon	Tewskbury Twp.	16.3	8.2	13.5
Penn Silt loam	Somerset	Hillsborough Twp.	12.6	5.6	10.5
Penn Silt loam	Hunterdon	Delaware Twp.	12	5.3	10

Table 2. Summary of infiltration rates of New Jersey Soils

	Average infiltration rates (in./yr)			
Soil Texture	*Landscaped*	*Unvegetated*	*Agriculture*	*Overall*
Sandy loam	12.8	8.4	11.3	10.9
Sand	16	13.6	15.2	15
Loamy sand	13.1	9	11.6	11.2
Loam	13.8	6.7	11.6	10.7
Silt loam	12.3	5.4	10.2	9.3
All soils	13.5	8.5	11.8	11.3

Table 2 indicates that an 11 in/yr infiltration is representative, on average, for sandy loam, loamy sand, and loam soils. Silt loam soils have slightly lower infiltration rates, while sand soils yield rates a few inches higher. As discussed in the generic standards section of this document, it was decided to use sandy loam soil texture as the generic soil type for New Jersey, as it was felt that use of a sand soil would be overly protective for much of the state. The results above confirm that assuming an infiltration rate of 11 in/yr is adequately protective for sandy loam soil and the other remaining soil textures.

APPENDIX F
Investigation of Transport Potential of Immobile Chemicals

To determine which regulated chemicals would be subject to the immobile chemical policy, several simulation runs were conducted using the SESOIL model (Bonazountas et al., 1984). The basis of this model is described in Appendix G. The model was run using the generic environmental conditions and soil properties used for calculation of generic soil cleanup standards. Sandy loam soil properties were entered using recommended values from the model authors. The soil was assumed to be homogeneous. A central New Jersey weather station was selected (Trenton, NJ) as an intermediate location between northern and southern New Jersey. The vadose zone was assumed to be 10' thick, and 1' soil layers were designated. Input parameter values relevant to contaminant transport potential in the soil column are given in the table below:

SESOIL modeling parameters

Parameter	*Value*
Groundwater Depth (ft)	10
Bulk density of soil (g/cc)	1.5
Number of soil layers	2
Soil sublayer thickness (ft)	1
Intrinsic permeability (cm^2)	2.00E-09
Effective porosity (v/v)	0.25
Disconnectedness index	4
Time increment (days)	1
Length of run (years)	100
Climate station	Trenton, NJ
Organic carbon content	0.20%
Freundlich exponent	1

Under these conditions, the SESOIL model yields an annual average recharge to groundwater of 11"/year, equivalent to the value estimated using an NJGS method. (Appendix E).

Several simulations were conducted using a model chemical. For these simulations, all chemical properties except the K_{oc} value were set to values that would maximize leaching potential (the Henry's law constant and the diffusion coefficient were set to 1E-6). Then, several simulations were conducted with different values for the K_{oc} parameter. The simulation times were 100 years. The distance that the model contaminant was predicted to move over a 100 year time period was tabulated for varying values of the K_{oc} parameter.

K_{oc} *(ml/gm)*	*Distance moved (inches)*
100,000	3.6
80,000	5.4
50,000	10.9
30,000	20.5

The results indicate that for chemicals with a K_{oc} of 50,000 ml/gm or higher, the distance moved will be less than one foot. For metals, this is equivalent to a K_d value of 100 ml/gm or greater.

APPENDIX G
Background Information on the SESOIL Model

The SESOIL model was originally formulated by Arthur D. Little and Associates for the USEPA (Bonazountas and Wagner, 1984). Since that time it has been revised and updated several times (Bonazountas et al., 1997). The model now has nearly a 20 year history and has been subject to several laboratory and field validation studies (Bonazountas et al., 1997; Melancon et al., 1986; Sanders, 1995).

The SESOIL model has become fairly well established and has been accepted by several state agencies and the USEPA for calculating remediation standards. Some of the states routinely using SESOIL exclusively or SESOIL with AT123D (a ground water transport model) are Oregon, New Hampshire, Wisconsin, Massachusetts and Hawaii. The models may be useful for site-specific remediation standard calculations when 1) there is a clean zone of soil between the contamination and the water table, or 2) when ground water plume modeling is desired.

The SESOIL model accounts for the contaminant processes of advection, volatilization, degradation, and surface runoff (Bonazountas and Wagner, 1984, Bonazountas et al., 1997). Precipitation is generated using a statistical formula that incorporates monthly New Jersey climate data. Water transport is calculated via the statistical water balance dynamics theory of Eagleson (1978). The model includes the mechanisms of runoff, infiltration, evapotranspiration, and ground water recharge. The capillary fringe effect is also included. Contaminant transport downward is calculated via advection using the retardation factor. The factor allows calculation of the distance of contaminant transport during each time step. The soil column is considered to be layered into several compartments. Contaminant entering a soil compartment is considered to be immediately mixed through the entire compartment. Vapor phase transport is also modeled (upward direction only) to allow calculation of contaminant volatilization. Various options for contaminant degradation are also included. However, at the present time, the Department only allows for first-order degradation of contaminants, and only when site-specific determination of degradation rates is made. An appropriate method should be submitted to the NJDEP for approval. An exception to this guidance may be made for benzene, toluenes, ethylbenzenes and xylene compounds, which may degrade rapidly in the vadose zone under certain conditions (DeVaull et al., 2002; Howard et al., 1991). Under these conditions, a generic half-life of 1 month may be used in SESOIL provided aerobic conditions in the vadose zone can be demonstrated. This value acknowledges the importance of degradation for these contaminants, while remaining adequately conservative. Actual half-lives in the field are typically on the order of days or weeks (Howard et al., 1991). When using SESOIL, free or residual product may not be present pursuant to N.J.A.C. 7:26E-6.1d.

<u>Using SESOIL</u>

While SESOIL incorporates numerous concepts into an extensive software code, the number of input parameters required to run these models are minimal. New Jersey climate databases and United States Department of Agricultural Soil Conservation Service soil series property databases are included in commercially available versions of the model, as well as guidance on input parameter selection.

Description of the AT123D Model

The AT123D model was originally developed by Yeh G.T (1981). AT123D is an analytical ground water three-dimensional contaminant transport model. It computes the spatial-temporal concentration distribution of contaminants in the aquifer system and predicts the transient spread of a contaminant plume through a ground water aquifer. It accounts for 1) advection of the chemical with the water flowing through the aquifer, 2) dispersion of the chemical via hydrodynamic dispersion and molecular diffusion, 3) adsorption of contaminant to aquifer solids, and 4) contaminant decay. Pre-approval is required from the Department to evaluate biotic or abiotic contaminant degradation of contaminants on a site-specific basis.

<u>Using SESOIL/AT123D</u>

While the SESOIL and AT123D models incorporate numerous concepts into an extensive software code, the number of input parameters required to run these models is minimal. New Jersey climate databases and United States Department of Agricultural Soil Conservation Service soil series property databases are included in the model, as well as guidance on input parameter selection. For use on New Jersey contaminated sites, the Department has assigned default input parameter values. When adjusting the default scenario for site-specific purposes, the Department has set restrictions on how the model may be used, what input parameters may be changed, and what restrictions are imposed on their modification. Guidance on the use of SESOIL and AT-123D may be obtained from the case team.

APPENDIX H
Derivation of Equation 6

The Synthetic Precipitation Leaching Procedure (SPLP) test results and the total soil analysis results may be used to determine a sample-specific K_d value for each soil sample that yields a measured aqueous concentration above the Minimum Detection Limit. The K_d value is applicable to both organic and inorganic contaminants, since it is a direct measure of adsorption to soil, rather than derived from soil properties such as organic carbon content. As explained in the USEPA Soil Screening Level Guidance Document (USEPA, 1996b), the equation for K_d is defined as the ratio, at equilibrium, of the contaminant concentration in the sorbed phase to that in the aqueous phase (Equation 12 in USEPA, 1996b):

$$K_d = \frac{C_s}{C_w} \qquad \text{i}$$

where C_s is the sorbed concentration of contaminant (mg/kg), C_w is the aqueous phase concentration in soil water (mg/L), and K_d is the soil adsorption coefficient (L/kg). When using the SPLP procedure described in this document to determine a sample-specific K_d value or cleanup criteria, it is also necessary to determine the total soil concentration of contaminant, (C_T, mg/kg) in the sample prior to extraction. The total mass of contaminant in the soil sample may be therefore described as $C_T M_S$, where M_S is the dry weight of the soil sample submitted for SPLP testing (kg). After equilibration with leaching solution, the total mass of contaminant leached may be calculated as $C_L V_L$, where C_L is the concentration of contaminant in the leachate solution (mg/L), and V_L is the volume of leachate (L). This mass may be subtracted from the total mass of contaminant originally in the soil sample to give the mass of contaminant still adsorbed to the soil after the SPLP experiment. The equilibrium concentration of the contaminant in the sorbed phase after the SPLP experiment may then be calculated as

$$C_T M_S - C_L V_L / M_S. \qquad \text{ii.}$$

Since the equilibrium aqueous phase concentration of contaminant after the SPLP extraction is C_L, the soil adsorption coefficient, K_d, may be expressed as

$$K_d = \frac{C_T M_S - C_L V_L / M_S}{C_L}, \qquad \text{iii.}$$

which is equivalent to Equation 6 in the basis and background document.

APPENDIX I

Determination of the Dilution-Attenuation Factor (DAF) for generic remediation standards

The flow rate of an aquifer is calculated by multiplying its hydraulic conductivity, ***K***, by the hydraulic gradient, ***i***. This flow rate is used in the equation for calculation of the dilution-attenuation factor (DAF), which in turn is used in the partitioning equation for calculation of generic cleanup standards. A default flow rate of 30 m/yr was determined for calculation of the DAF.

To develop this flow rate, the Kirkwood-Cohansey aquifer in southern New Jersey was selected as a reasonably conservative scenario for evaluating potential groundwater impacts from overlying contaminated soil. This 3,069 square mile aquifer is relatively shallow, lies underneath soils with considerable sand content, often exhibits low flow rates due to generally flat terrain, has the most field measurements of ***K*** of all the formations in New Jersey, and represents a large percentage of the total area of the Coastal Plain physiographic province. Because it is extensive, and vulnerable to contamination, it was selected as an appropriate aquifer to develop a reasonably conservative, generic DAF value.

A Geographic Information System (GIS) was used to determine a generic aquifer flow rate for the Kirkwood-Cohansey aquifer. The approach involved multiplying hydraulic conductivity and aquifer slope data layers. A recent research project conducted by the Department's Division of Science, Research and Technology has resulted in the availability of a GIS grid data layer of hydraulic conductivity values for the Kirkwood-Cohansey aquifer over its entire area (Vayas et al., 2004). The layer was developed using 109 high quality measured values for hydraulic conductivity from water allocation pump tests. Values between the measured points were interpolated using Bayesian mapping techniques. Bayesian methods are a significant advance beyond kriging or Radial Basis Function methods because they are able to formally incorporate theoretical and empirical knowledge base information pertaining to groundwater flow within the interpolation.

To obtain a hydraulic gradient data layer, two approaches were used. The first used a generally accepted procedure for the New Jersey coastal plain that assumes the hydraulic gradient is approximately equal to one-half the topographic surface gradient (Spayd and Johnson, 2003). NJGS has developed an extremely high quality topographic GIS layer that based on a 10 meter grid. In this grid the area coincident with the Kirkwood-Cohansey aquifer contains over 77 million grid cells. The topographic grid was clipped to the Kirkwood-Cohansey boundary and the elevation values were translated into topographic slope values (decimal percent) using GIS conversions. The topographic slope values were then divided by 2 to obtain a hydraulic slope value in each grid cell. The grid cell size was then enlarged (number of cells reduced to 17 million) to enable processing with the horizontal conductivity grid layer. This approach has the advantages of 1) an extremely high quality input data set, and 2) generating slope values that are consistent relative to each other across the entire aquifer. A disadvantage is that the effect of groundwater pumping, which may affect the hydraulic gradient, is not considered.

In the second approach to calculate a hydraulic gradient, existing GIS contour files of groundwater elevations from 8 separate US Geological Survey (USGS) watershed studies were edge matched together (Watt et al.(1994, 2003), Charles et al. (2001), Johnson and Charles (1997), Johnson and Watt (1996), Lacombe and Robert (1995)). The mosaic line work was converted to a triangulated irregular network file (TIN), then converted to a grid file. The grid's water table elevation values were converted to slope values. This approach has the advantage of using actual measured water table elevations, which should reflect the effect of water table pumping. A disadvantage of this approach is the use of data points collected over 8 different time periods, 8 different input data densities, and 8 different levels of data quality. Because water table elevations vary with time, the consistency of these data points relative to each other is uncertain.

To determine the aquifer flow rate, the hydraulic conductivity grid layer was independently multiplied by each of the 2 hydraulic gradient grid layers. The aquifer flow rate based on the topographic slope yielded a mean, median and mode for the aquifer flow rate of 101, 51 and 1 m/yr. The second approach based on the USGS water table elevation grid layer yielded mean, median and mode values of 12, 9 and 2 m/yr.

Given that both methods for calculating the hydraulic gradient have significant advantages and disadvantages, that all summary values have been observed in the aquifer, and that neither approach was clearly preferable; both were used to estimate a representative aquifer flow rate. The average of the two median values (51 and 9 m/yr) was used, which gives a flow rate of 30 m/yr. The median, rather than the mean, of each method was used since the mean may be overly influenced by outliers in the data sets while the median represents the mid point in the data. Substituting this value for the ***K*i*** product into the DAF equation (along with appropriate values for the other parameters), a dilution-attenuation factor of 12 is calculated for purposes of calculating generic soil remediation standards.